CONSEIL INTERNATIONAL DES UNIONS SCIENTIFIQUES
INTERNATIONAL COUNCIL OF SCIENTIFIC UNIONS

UNION GÉODÉSIQUE ET GÉOPHYSIQUE INTERNATIONALE
INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS

Bulletin of the International Association of Scientific Hydrology

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VI^e Année - N° 4

DÉCEMBRE 1961
DECEMBER 1961

Bulletin paraissant 4 fois par an

Published on behalf of
THE INTERNATIONAL ASSOCIATION OF SCIENTIFIC HYDROLOGY
by
CEUTERICK
153, RUE DE BRUXELLES
LOUVAIN (Belgium)

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I. PROPOS DE L'ÉDITEUR
I. REMARKS & NOTES BY THE EDITOR

1. This issue does not yet present the scussions of the Symposium of Athens. ou will however find in it the results of e meeting of the Council.

The minutes of the Symposium will presented in the issue VII N° 1.

1. Ce bulletin ne présente pas encore les comptes-rendus du Colloque d'Athènes. Vous y trouverez ceux des réunions du Conseil à Athènes.

La Rédaction espère pouvoir présenter les discussions du Colloque dans le Bulletin VII N° 1.

2. All the hydrologists who took part at e meeting of Athens found that it was a od succes. 120 attendants and about 35 dies coming from more than 30 countries me together. 80 communications were esented, each of them followed by a very teresting discussion stimulated by the inted text.

2. Le Colloque d'Athènes fut cependant, de l'avis de tous ses participants, un grand succès. 120 représentants de plus de 30 pays y assistaient. 80 communications furent présentées et donnèrent lieu à des discussions très fécondes, grâce à l'impression préalable.

3. Some new inquiries on the Sympoum of Bari and of Obergürgl are presented this Bulletin.

3. Quelques indications nouvelles sur les colloques de Bari et d'Obergürgl sont données par le présent Bulletin.

4. We are glad to remark that during is year, numerous countries sent their ydrological bibliography : Poland (2 years) zechoslovakia, Sweden (6 years), Switzernd (3 years), United Kingdom (5 years), ungary (4 years), Austria (5 years), Many her countries will follow.

4. Nous sommes heureux d'annoncer qu'au cours de cette année de multiples pays ont envoyé leur bibliographie. Nous citons : la Pologne (2 années), la Tchécoslovaquie, la Suède (6 années), la Suisse (3 années), le Royaume Uni (5 années), la Hongrie (4 années), l'Autriche (5 années). De nombreux autres pays se préparent.

5. The interest for this Bibliography uring the meeting of the Commission for ydrological Meteorology of W.M.O. is a ood stimulant showing that the collabotion between our two Organizations may ecome very convenient.

5. L'intérêt manifesté par la commission de Météorologie hydrologique de l'O.M.M. est un stimulant qui indique notamment combien la collaboration entre nos deux organisations est favorable.

6. We are very glad to see the growing interest for the Bulletin. The development of the scientific part is one of the best marks of this interest. But we should like that our readers send us all kinds of inquiries that may have an interest for the hydrologists: new hydrologic organisations or development of existing organizations, education of hydrologists, news from wellknown hydrologists, etc.

We regret that the extensive report of the British National Committee published in the Bulletin VI N° 1 was not followed by other documents of this kind, presented by other countries.

6. La rédaction marque toute sa sat faction de l'intérêt croissant pour le bullet Le développement de la partie scientifiq en est le meilleur signe. Mais il faudr aussi faire parvenir à la rédaction des in cations pouvant intéresser les hydrologue naissance et développement d'organisatio s'occupant d'hydrologie, nouveautés da la formation des hydrologues, nouvell d'hydrologues connus, etc. La rédacti déplore que le bel exemple du Royaur Uni publié dans le bulletin VI N° 1 n'a pas encore été suivi par d'autres Natior

II. PARTIE SCIENTIFIQUE
II. SCIENTIFIC PART

A PROPOSAL FOR INTERNATIONAL COOPERATION IN HYDROLOGY

BY A PANEL OF HYDROLOGISTS (*) (USA)

In our times science has become a vital instrument for fostering international comity. Among all the world's resources, water occupies a position especially adaptable to international cooperation.

Water occupies a central role in the life cycle. Water develops soil, soil feeds vegetation, and vegetation needs water-all these factors compose a single cycle. It is a cycle of which man is a part. Thrust from that cycle, he dies. Hydrology, the science of water in the earth, occupies an area in the world of science that can make great beneficial impact on society and show the best of western science to the world. Indeed, water development has become a source of strength in much of the world. Large sectors of the various technical assistance programs are already committed to furthering water development.

The population of practically all nations and continents is increasing at an alarming rate, and, furthermore, is concentrating throughout the world in huge metropolitan complexes. The problem of feeding these people, of disposing of their wastes, and of providing them with sufficient water of good quality for all industrial as well as social and domestic needs will be enormous. A thorough knowledge of the land and water resources available to accomplish this task, organized in such common terms as to be readily understood or usable by all nations, is essential for this purpose.

The Panel proposes, therefore, that a plan of international cooperation in hydrology could serve well to advance the science as well as to advance the well being of all nations.

Advantages of an international program

1) The occurrence and distribution of water in any country is a consequence of the circulation of water on the whole planet. Water in one country cannot be studied completely in terms of that country alone.

2) One of the dominant needs of all countries of the world is better knowledge of the occurrence and distribution of water. Information is slowly and costly gained in any one country. Because of the diverse nature of the terrain and climates, no one country, including the United States, can gain a satisfactory accounting of the behavior of water in all of its domain within a time short enough to be useful. A plan of joint study in which the several countries undertake to study of the problem by covering a wider range of geologic and climatic provinces can do the job most efficiently.

(*) W.B. Langbein, Chairman; W.E. Thurston, Secretary; William Benson; A.L. Cochrane; W.E. Hiatt; O.C. Hopkins; C.H. Wadleigh.

3) In practical terms, the result would be to improve greatly the ability of man to und stand his environment and to manage its resources. The potential reality of such practi benefits that accrue from a scientific program, has been illustrated already in the geophysi sciences.

4) An international program that widens the scope of study will serve to interest oth scientists in hydrology and to stimulate education in that field of science.

5) Proposals for the modification and improvement of weather, climate, and water resou ces have been proposed by authorities at various times. These vary from simple cloud-seedi operations to vast projects for reorganizing energy and water resources such as those propos for the Mediterranean and Lake Chad basins or even for the diversion of ocean currents, t use of nuclear energy, or the spreading of carbon black on the polar icecaps to melt the ice, methods of raising the temperature of the adjacent sub-arctic land masses. Lesser schemes f water management would, in some instances, still involve international waters.

Any such efforts at extensive climate or resource modification could have profound clima and hydrologic effects upon areas lying beyond the target area of immediate benefit, and cou alter the sociological or economic life of whole populations.

Some of these schemes are viewed seriously in some quarters as eventual possibiliti Such programs should not be undertaken on an irresponsible, unilateral basis, but should studied, understood, and, if feasible, agreed upon on a worldwide international basis. Hydr logic effects, especially of an international character, are an important element to be studied connection with such programs, as well as with respect to existing programs for world impr vement in diet, health, and economic endeavor.

6) Hydrologic data regarding some of the rivers and other water bodies involved in inte national water problems are meager or poorly organized. Possible influences of climate, mete rology, and geology on water resources involved in international schemes are not as yet ful understood.

A SET OF HYDROLOGIC PROBLEMS

The central problems of water development are to maximize the usefulness of the resour for the farm and the home, for power, and for navigation, while at the same time, to minimi the adverse consequences of floods, pollution, salinization, and river degradation. We propos therefore, a plan of study that will contribute materially to the solution of such matters concern to the world community and that will advance the underlying science. The plan study would also aim to provide information in support of international technical assistan programs in advance of, not after, troubles develop.

An illustration of the kinds of water problems just cited and as given below was therefo the base upon which to draw the proposed plan. However, because hydrology is the comm scientific link in the solution of all these problems, it is most practical to establish the wo plan on a scientific frame.

Water for irrigation

Three hundred million acres are irrigated in the world, and the hope of increasing fo production in many of the overcrowded but newly developing countries reposes in success irrigation.

Irrigation is a simple process--watering crops. But in that act, as the history of that ancie art demonstrates, man introduces a vast chain of hydrologic variables in which error dooms t undertaking to an eventual unsuccessful end. More than money is lost--also jeopardized is t health and welfare of those whose livelihood depends on irrigation farming. This was t consequence in the long-abandoned works in Mesopotamia which was repeated in the ea attemps at irrigation in this country.

The keys to successful long-term irrigation lie in three balances-- the water balance, the salt balance, and the sediment balance. Improper knowledge of the water balance leads either to water shortage or water logging; neglect of the salt balance incurs either the hazard of salinization or the waste of nutrients through excess leaching; inadequate consideration of the sediment balance introduces either erosion of lands and canals or deposition and siltation. At this time 100,000 acres of irrigated land go out of production in Pakistan each year because of imperfect water and salt balances. These three balances therefore constitute matters of grave concern to all countries with large irrigation economies. Data on the operation and processes that control these balances in one country are useful in another; a program of international cooperation that includes a study of the water, salt, and sediment balances can be productive of very practical results.

Food production, soil conservation, and watershed management

All life on earth is dependent on the capacity of the green leaf to convert light energy into food energy. But the leaves of food plants use only about 2 percent of the light energy impinging upon them in this conversion. Yet, some 80 to 85 percent of the net radiation on the leaves effects evaporation of water (transpiration) from these leaves. Thus, this enormous impact of radiant energy on vegetated lands commands over two-thirds of the water budget of the United States for evapotranspiration and consequent movement into the atmospheric arc of the hydrologic cycle. The percentage is even greater in the newly developing countries which are mainly in tropical or arid regions. The staggering demands for the world's food supply make it imperative that means be sought to maximize photosynthetic efficiency in crop plants while this inexorable impact of the sun's radiation removes a major portion of the earth's water supply by evapotranspiration.

Barren and denuded soil will not grow plant life (i.e. food) regardless of the adequacy of water supply, but the ravages of storms and running water can denude and ruin a productive soil. Past civilizations have come to their demise while learning this the hard way. In fact, society pays double indemnity for eroded soil, since that moving downstream becomes a burden of costly sediment in channels, harbors, and reservoirs. Soil conservation has as its objective the maintenance of the maximum productive capacity of our soils through infinite time. This requires the application of land-use practices which minimize potential depredations of wind and water while maximizing beneficial use of water in the soil-moisture reservoir.

Water running wild over the land never heeds the artifacts of legal and political boundaries. Research gained in one country may be useful in another. But shortness of record and limited range of experience severely circumscribe the work that can be done in a single country. It takes many generations of men to determine how soil and water in the various climates react to produce fertile land on the one hand or destructive erosion and floods on the other extreme. Given the world as a laboratory in which to conduct research, the learning process can be accelerated.

Power production

Hydroelectrical power production in many countries is a condition to industrial growth and, therefore, waterpower schemes are prominent features of national plans for economic development. Profitable generation of electrical energy, however, depends heavily upon an assured supply of water as determined from analyses of records of riverflow, a highly variable phenomenon. The plan for international cooperation, therefore, highlights information on the occurrence of riverflow in time and place.

International rivers

Rivers very commonly form international boundaries. Or even more usual, rivers cross international boundaries. Thus the occurrence or non-occurrence of water in these channels are

directly matters of bilateral attention; however, the means upon which the division of water based are of concern to the international community at large. To establish equity in the divisi of the resource and of the responsibilities for its management requires not only uniform syster of obtaining data of international acceptability*, but sound methods of determining the hydr logic effects of proposed schemes of development. A program for international cooperati in hydrology can, to this extent, foster international amity.

Pollution and contamination

Man draws his water from the natural environment and every use of water, whether the home or factory, or on the farm, degrades some aspect of the water. Man returns water to a environment no longer natural, and the extent to which his degradation of the quality of th water impairs the environment from which he again draws his supply depends on the hydrolog of the water system. The earth is the only place in or on which wastes may be stored, or disperse and for that reason, safe waste disposal is closely linked to study of the earth. Because near all wastes, animal, vegetable, mineral, or radioactive, are produced in liquid solutions or su pensions, they are highly mobile and enher the hydrologic cycle of the earth.

Dilution and dispersion cannot be counted upon, for there are processes leading isolation and concentration as well. Under certain hydrodynamic conditions, not yet understoo contaminants in rivers tend to occur in streaks unmixed with the main body of flow. The sam kind of process occurs in the ground where variations in permeability tend to establish preferre paths of water movement.

There are chemical as well as hydraulic reactions. Ionic adsorption and interchange between water contaminants and earth materials can alter the chemical composition of th water and so operate as to retain and therefore concentrate contaminants.

Hydrology is also closely linked to the control of waterborne insect disease vectors. Fo example, storage reservoirs and canals can cause a great increase in the number of malar mosquitoes and even an epidemic of this disease. However, by controlling the levels and mov ment of the water, mosquito breeding can be prevented.

Advancing civilization compounds man's anxiety for this health. The few illustratio cited show that the long-term safety of man on this planet depends on how well he understanc the operations of the hydrologic cycle. All nations share in this concern, and tehrefore th program includes studies in this field.

Flood protection

Destruction of life and property by floods exacts a frightful toll throughout the worl The loss can be averted through flood-control works and by regulation of the use of land bordering rivers provided information on the occurrence of floods is available.

The overflow of rivers in flood is a consequence of the interaction of a complex set of facto beginning with a storm or rapid snowmelt. The shedding of the storm rainfall or snowmelt int the rivers depends on the slope of the land, the vegetal cover, and the soil and its moisture stat at the time. The height of the flood and its progress in the river system depends on the geomor phology and hydraulics of the river system.

Floods, therefore, differ widely among themselves on the same river and among differer rivers depending on the particular combination of factors that create each flood. For tha reason, it is essential in this field to gather and examine many facts on flood occurrences. A international program, which assures that data are obtained in a systematic manner, offers th possibility of multiplying the range of facts enormously, to the advantage of all.

(*) The Secretary General of the United Nations reported "serious gaps in the internation exchange of experience are the absence of continuing worldwide programmes with regard to bas hydrological data and to study of the integrated development of water resources" (E/2205, 25 April 195 p. 46).

Forecasts of water supply

Those who plan on the use or the management of water can often modify their plans in accordance with their expectations of the quantity of water that will be available to them.

With advance knowledge of the streamflow that will be available, the reservoir operator can more effectively control the storage allocations and drafts on his various reservoirs. The hydroelectric power producer can determine from such forecasts his probable need for thermal generation.

When the flow is low he can carry baseload with thermal generation and use hydroelectric for its most effective purpose, peakload. When water is abundant, he may use streamflow in excess of storage capacity to carry baseload and use thermal power for peaking.

The irrigation farmer, with advance knowledge of the probable water supply for the following summer, can select crops and acreages compatible with the water he expects to be available. He need not plant what he later finds he cannot irrigate, and he can plant larger than normal acreages when the water required will be available.

Forecasts of water supply are now being made, not only for daily or weekly periods, but as much as six months in advance, in regions where the major runoff is from the accumulated mountain snowpack of winter. There is a need for forecasts over both shorter and longer time periods. This practical application of hydrologic information can be extended in many countries provided many improvements can be made in the forecast techniques and in the techniques of basic observation. An international program of research and development in this field would be of tremendous benefit as the need for optimum conservation and utilization of the basic water supply increases.

A plan for a scientific program

The central water "problem in our times is to devise means for obtaining and protecting water efficiently and economically. Repeated shortages, persistent deficiencies, damaging floods, and polluted streams demonstrate abundantly that mankind has no solution to the long-term "problem" of too many people in places where there is too little water, and the probable ultimate problem of not enough water anywhere for too many people everywhere.

The main practical problem, therefore, is to get more and more use from a given amount of water. This, too, is partly an engineering and management problem—to improve efficiency. But as the margin between supply and demand narrows, efficiency becomes increasingly a problem of improved hydrologic knowledge. Thus, it is a problem of science, because the present state of hydrologic knowledge is not sufficient to enable the engineer or water manager to cope with complicated water problems in a scientific manner.

To increase the scientific basis of water development, therefore, is a means toward better solutions of water problems. But water problems should not be confused with hydrologic problems, because the latter must be solved first.

The international program envisioned in this outline centers around hydrology and hydrologic problems with the aim to improve the basic science. The plan of international cooperation we propose should cover a 10-year period, because it is in the nature of the occurrence of water, that a period of observation of that length is required for minimum results. An outline for an international cooperation in hydrology, prepared by R.L. Nace, special advisor to the Panel, which accompanies this recommendation, provides an example of the practical and profitable scientific objectives and of a plan of operations.

A PLAN FOR INTERNATIONAL COOPERATION IN HYDROLOGY

PANEL ON HYDROLOGY (USA)

OBJECTIVES AND PROGRAM [1]

Hydrology — A Global Science

Water, in some form and amount, is present in every square inch of the earth's surface and in every cubic inch of the earth's crust to substantial depth. Nearly all this water participate in the hydrologic cycle. The residence time of water in any one place or environment varie from a few minutes to a few thousand years, so there is no "cycle" in the sense of a singl recurring sequence of events involving the same masses of water. Rather, there is one gran and complex cycle — here called the hydrologic geocycle — which comprises successivel smaller hemispherical, continental, regional, and local cycles. Hydrologists have scarcely looke at anything but the local cycles and specific parts of regional and continental cycles.

There is a continual appeal for water studies, bolstered by recurrent grim warnings abou water problems by 1980, by 2000, and so on. As a matter of fact, most available hydrologi manpower already is being applied to the descriptive task of estimating, measuring, and descri bing the water supplies in parts of local and regional natural water systems. Most studie proceed as though each problem were an isolated case, unaffected by those around it and havin no impact beyond the arbitrary boundaries chosen for the study. We should not make th mistake of believing that, once we can measure a thing, we know something about it. On th contrary, we know very little until we can explain what we have measured. No hydrologi system can be explained by treating it as a closed system with only a few parameters, becaus no system has closed boundaries for all of its many parameters. What are the parameters

The parameters, to cite only a few, range from solar insolation to exothermic reactions i the earth's interior; from precipitation on Mt. Everest to water expressed from compacting sediments on the floor of the ocean deeps; from stratospheric vortexes over Antarctica to convective eddies over Phoenix; from the discharge of surface water by the Amazon River to the calving of ice from the frozen cap of Antarctica; from the evaporative deposition of sal in the Gulf of Kara-Bogaz to the buried salt beds, hundreds of feet thick, beneath large area in 23 of the United States; from the microflow phenomena of ground water moving through earth's aquifers to the macroflow of oceanic currents; from the birth of cosmogenic carbon 14 high in the atmosphere to the slow ticking of atomic clocks in the buried organic sediment of lakes and rivers; and from the monsoon of the Indian Ocean to the sirocco of the Sahara Finally, man and his works also are parameters.

Man and Water — A Global Problem

It has been written that man is the one disorderly element in an otherwise orderly environ ment. Man has mastered his own ecology to some extent, but in doing so he has added to it complexity, for good or ill. Neither the lithosphere, the hydrosphere, or the biosphere is a distinct entity. They are inseparable, and each overlaps the other and influences it in man ways. They have always interacted, and the only change since prehistoric time is that man i becoming an increasingly dominant factor in the biosphere and is creating far-reaching imba lances. By his insistence upon unlimited freedom to reproduce, and by his demand for an endles variety of industrial and other products, man now threatens the stability of his own ecolog by destroying resources and burdening his ecology with the waste products of this own activities

[1] Prepared by R.L. Nace, special advisor to the Panel on Hydrology.

The average water study is motivated by and revolves around the fact that a community or area has a problem of water supply or water quality. To what extent will such studies solve water problems ? These studies will provide no permanent solutions for any problem, because the problems of today always are replaced by the larger problems of tomorrow. We can expect, at best, only to be able to cope with constantly changing situations by a continuous series of decisions.

The most urgent need, therefore, is not to struggle with existing problems (these can be met for the time being), but to improve our ability to cope with the vastly more complex problems of a future that is almost upon us. In other words, we must improve our scientific base of operations.

Men talk of remodeling the earth's weather system, of wringing more water from the passing cloud, and of creating more clouds where we want them. Obviously, the possibilities should not be neglected, because such things may be done, and hydrologists will have a part in the doing. Meantime, however, it seems practical to increace the efficiency of our use of the rain that falls naturally. «Manufactured rain» will be very expensive indeed if we use it no more efficiently than we do natural rain, so the critical need is to learn how to conserve more of what we already have. This will require more understanding of the processes that operate the water cycle, and this understanding must have a broader base than the river basin or the piece of a continent called a nation.

Global Means International

No nation occupies an entire continent. (The subcontinent of Australia is an imperfect exception.) No continent has a closed hydrologic system, but each is a part of a global system. Therefore, no nation can learn by itself, within its own boundaries, all that it must know about water and the hydrologic cycle. None can completely learn even its own local water balance within the continental system. On the other hand, no nation can or would send its own scientists to work in the area of other nations. Cooperation among nations is required, so the task is international.

Benefits expected from international program

Each natural water system is dynamic, and each system changes with (a) time, and (b) manipulation. The time dimension is a main reason why hydrologic systems are so difficult to describe or define. Each system includes, not alone the factors that exist at a given time, but also everything that happens during a span of time. The difficulty that the system is "open" largely vanishes in the largest (global) system, which is essentially closed. The whole system has been too long neglected, and one can expect much benefit from international attention to the whole, as well as to the parts.

Improved International Understanding

Science is an intellectual meeting ground which can be kept relatively free from excessive nationalistic, chauvinistic, or ideological influences. Most scientists are eager to work in an atmosphere of free communication and exchange of ideas. International cooperation accords with the policy of the United States Government. Few fields of such cooperation are more fruitful than science, as we have seen already in the field of geophysics and as we are beginning to see in oceanography and atmospheric sciences.

The success of international cooperation in hydrology, like other scientific ventures, will depend largely on scientists themselves, on their ability to plan with broad vision, their willingness to compromise small differences that have little bearing on broad objectives, and their adherence to the principles which underlie international cooperation. Scientists, for example,

must avoid actions or ventures that have political implications, and they must guard against political implications that may attach themselves to ventures.

Increased Scientific Information

A wisely designed and carefully executed program of international cooperation in hydrology would develop widely useful scientific information. For a single example, consider synoptic data on hydrologic phenomena. ("Synoptic" here has the double sense of "comprehensive" and "essentially simultaneous.") Synoptic data for wide areas are available now only for a few factors (such as precipitation and temperature) in the hydrologic cycle over wide regions, or for several factors in smaller areas. Virtually no synoptic data are available for important factors like soil moisture; the instantaneous (still-life) content of water in stream channels, lakes, and the ground; earth-tide fluctuations of water levels in wells; elastic response of ground-water aquifers to seismic shocks; seasonal changes in the amountsoof water resident in the oceans and on the land; and many other phenomena.

Advancement of Scientific Hydrology

Hydrology, a synthesizing science, is generally recognized in Europe as a specific scientific discipline, but is less widely recognized in the United States. Moreover, few people anywhere actually call themselves hydrologists. This failure to identify the discipline and its practitioners has retarded progress in the science itself. An analogous situation prevailed 20 years ago in geophysics, which was virtually unrecognized among earth scientists at that time. Now, however, geophysics is well-established, and the planning and development of the IGY program accelerated universal recognition. Similar recognition is needed for hydrology.

Improved Education in Hydrology

Few colleges or universities offer education in or for hydrology except in a narrow sense (e.g., "hydraulics"). University curricula need revamping and broadening to train more scientists who are better equipped to deal with scientific hydrology. (See report of the Ad Hoc Panel on "Education in Hydrology".) Few people or none have been trained as hydrologists. A few individuals have *become* hydrologists.

A broad program of international hydrology, with adequate university participation, would help to focus academic attention on hydrology and lead to improved curricula. It would also focus the attention of students on the fact that there is a career field of hydrology.

More and Better Hydrologists

The combination of gains from international cooperation would lead to development of a larger fraternity of trained, practising hydrologists who would wear that label. At present, even some of the larger countries of the world have few hydrologists or none. Many small countries have none at all. For many years the United States has supported, through the International Cooperation Administration, a program to send American hydrologists to countries overseas to help study their water resources and water problems, to train hydrologists, and to help organize and develop government water-resource agencies. This program has been mutually beneficial. Nevertheless, the rate at which water problems are growing makes it imperative that each country develop more rapidly its own capability to deal with water situations. An international program would contribute to that end if only by arousing universal interest in the science. The domestic situation in the United States is such that we can ill afford to export first-rate hydrologists. Enlightened self-interest is for all countries a valid basis for promoting a program.

Summary of problems and benefits

All nations need rounded knowledge about principal aspects of the hydrologic cycle, the natural forces that control those aspects, principal factors that produce given effects, the place of human actions and events in the hydrologic cycle, and what can be done to influence natural processes toward man's ends.

Vigorous action is needed in all aspects of hydrology from the academic training of hydrologists to the application of diverse skills to analysis of a wide variety of hydrologic data.

Financial austerity has been the lot of scientific hydrology but the needs of the science far surpass mere appropriations of more money. In the long run, with a view to future problems, it would be useless to try to strengthen hydrology without strengthening hydrologists. This requires stronger training of the current and future generations of hydrologists.

Investment in scientific research is not in the same category with investment in specific projects or in specific projects to gain specific pieces of information.

The purpose of the proposed international program is to strengthen the whole science, to broaden the base of world water facts, and to advance understanding of hydrologic processes, all leading to improved ability to bend the forces of nature to the benefit of man.

Desirable scope of program

The very existence of complex water problems is evidence that (1) available knowledge is insufficient to cope with situations, that (2) available knowledge is not being correctly or fully used, or (3) both. Deficiences in methods and knowledge can be removed by studies and investigations but, unless these are guided by some central idea or group of ideas, they may lead only to accumulations of data.

Data, Problems, and Ideas

Data are facts and facts are only history. But, though data are the essential grist of science, scientific study does not begin with data. Rather, it begins with ideas. Data which bear on no central theme can hardly lead to definitive conclusions and thus are hardly worth knowing. No need is apparent for programs, international or otherwise, which will merely provide data.

The working scientist sees a problem, an apparent anomaly, a difficulty. He discerns a possible solution or explanation, and he collects data which are then analyzed to determine whether they support or negate the explanation. The same general approach would be desirable in an international program.

The first step in an international program would be correctly to identify deficiencies in scientific knowledge and to evaluate ways in which these deficiencies hamper progress in the science.

Identification of deficiencies in knowledge (problems in hydrology) is in itself a major topic in which international collaboration would be desirable.

The scope of hydrology is so wide, and the applicable disciplines ramify so many aspects of physical and biological sciences, that a program of international collaboration could not cover the whole field effectively. International hydrologic studies obviously would concern continental hydrology, including glaciers and icecaps, but they necessarily would also impinge upon atmospheric sciences and oceanography. Therefore, current international work in oceanography and the national program in meteorology and atmospheric physics would have great interest and value in the hydrology program. Much useful information will already be available by the time a program begins.

Early Limited Objectives

A second step in development of the program would be to specify the kinds of data, studies and other means which seem likely to lead to corrections of deficiencies. An early need in the program will be to develop ideas to be tested. Owing to the shortage of hydrologists and of other scientists who are interested in hydrology, the early stage of the program may well be limited to some basic and elemental aspects of hydrology.

For a program of 10 years' duration, it may be advisable initially to restrict activity to a relatively few limited objectives which might be achieved in a few years.

Some fields of special interest may be suitable for study, but limited objectives might well be sought within the following general framework :

1. Hydrologic cycle, with special attention to continental precipitation, evapotranspiration, ground-water regimen, and runoff. Delineate the framework into which all water systems fit. Major components of cycles should be described with time and quantity dimensions.
2. Role of water in the geochemical cycle.
3. Role of water in the biological cycle.
4. Role of water in the geomorphic cycle.
5. Role of physical and biological sciences in hydrology.
6. Role of mathematics in hydrology and in the solution of water-supply problems.

These might be considered as preliminary forays (a) to focus general attention on the all pervading role of water in earth processes and human affairs, (b) to gain recognition that many scientific disciplines must be applied to unravel the complexities of water, and (c) provide a common meeting ground and language for the social, physical, and biological science. Item (c) is essential if scientific findings are to be a real basis for "doing something" about water problems.

Work Groups on Standardization

The planning of a program would require designation of one or more work groups or committees on standardization, because the products from work in all areas and topics should be directly comparable, one with another, without conversion of units or application of adjustment factors. To the extent that it is possible, agreement should be reached to standardize Units of Measurement, Techniques, Instruments, Terminology, and Base Maps. Standardization should take advantage of the facilities available in the Commission on Meteorological Hydrology of the World Meteorological Organization.

Among techniques, an example is estimates of potential and actual evapotranspiration. For each area or continent these should be made by comparable methods. Otherwise, the results may not be comparable.

The wide variety of instruments in use for measuring streamflow, soil moisture, precipitation, and other phenomena adequately illustrate the need for standard kinds of instruments.

The need for standard terminology hardly needs discussion, but terminology itself probably will be a topic for much discussion.

Base maps may be an especially difficult problem. No doubt only general specifications can be developed, because the adequacy of horizontal and vertical control for base maps varies extremely among countries of the world.

Scientific Symposia

Early in development of the program — possibly before any work is activated — international symposia might be held. The principal purpose should be to define fields of inadequate scientific knowledge to discuss the unknown rather than the known, to specify what kinds of

data and research are needed to close important gaps in knowledge, and to suggest means for closing the gaps.

Some program suggestions

The following outline includes suggestions for studies that meet one or more of the criteria outlined on preceding pages. These suggestions, some of which may be impractical, are advanced chiefly to illustrate the kinds of programs that would have immediate interest and value and would be apt to bear early fruit. From a list of this sort, a great variety of combinations might be chosen. Studies of these kinds could be national, continental, hemispheric, or global in scope.

I. *Hydrologic Atlas*

Hydrologic atlases are among the kinds of nonresearch products, many of which would not require high levels of professional skill, but which would contribute materially to knowledge about hydrologic phenomena. No organized data are available in standardized form on the several phases of water on all the continents, and few are available even for single continents. Atlas data would promote the objectives of domestic water-resources agencies in each country, and could be expected to help win general support for the program. Among possibilities for consideration are the following :

A. Isopleth and other maps

1. Precipitation
    a. Average yearly (depth and volume)
    b. Variability
    c. Drought recurrence
    d. Time trends
    e. Dissolved and entrained constituents
2. Runoff
    a. Equivalent depth
    b. Volume
    c. Percent of precipitation; ratio; precipitation/runoff
    d. Ratio, maximum, minimum
    e. Variability
    f. Time trends
3. Ground water
    a. Water table
    b. Saturated thickness
    c. Volume
    d. Temperature
    e. Permafrost
4. Soil moisture
    a. Average and range of deficiency
    b. Variability
5. Water budget
    a. Potential and actual evapotranspiration
    b. Retention of water in zones of aeration and saturation
    c. Gross loss
    d. Water yield

6. Water chemistry
    a. Streams and lakes
        w. Average total solids and hardness
        x. Variability
        y. Pollution and contamination
        z. Time trends
    b. Ground water
        w. Average total solids and hardness
        x. Variability
        y. Pollution and contamination
        z. Mining (depletion)

7. Sediment loads
    a. Yearly totals
    b. Seasonal distribution and variability
    c. Relation to runoff rates, etc.
    d. Time trends

8. Water use
    a. Total
    b. Consumptive
    c. Percent of availiable supply
    d. Time trends

B. For "key" locations

1. Diagrams of various kinds (histograms, duration diagrams, "mass" diagrams, etc.) to show variations and trends in precipitation, streamflow, and so on.

C. Summary data

1. Selected summary data to illustrate, amplify, or substantiate maps and other illustrations. (No data as end-products in themselves.)

II. *Benchmark Hydrologic Stations and Basins*

Benchmark hydrologic stations would be selected or established to measure (a) precipitation and dissolved and entrained constituents; (b) potential evaporation; (c) soil moisture storage; (c) runoff, including solutes and sediment; and (d) other hydrologic variables such as changes in stream-channel morphology.

The purpose would be to obtain coordinated correlative values of the several variables in given environments, and comparative values for unlike environments. Stations might be either (a) on coarse networks of continental scope or (b) along a few transects across major climatic or physiographic provinces.

Preferably benchmark stations should be in undeveloped areas that are likely to remain relativeley undeveloped for a long time. Some must, however, be in developed but stable areas. To evaluate the effects of the works of man, a few stations might be in areas where change is rapid and continuing.

To develop a benchmark-station program that will be manageable in size will be difficult. The idea may be impractical, but it deserves thorough consideration. Practicality may hinge to an important degree on the extent to which benchmark stations could be provided or serviced by existing observatories, field laboratories, military posts, experiment stations, ranger stations and the like.

. *Sample Specific Projects*

Following are brief outlines of some more specific project possibilities. These constitute ly a preliminary sample, the purpose being to illustrate the kinds of work that might be under-ken in a National Water Year and in an International Decade for Hydrology.

Following this series of outlines is another section, "Components of Earth's Water System" ich includes a working ouline. In that outline, topics are identified by a numerical system. otations such as "7.31" in the present section refer to numbered topics in the working outline.

Hydrogenesis (8.1)

The terms, "juvenile" or "magmatic" water are found in most textbooks on geology. But atively little scientific attention has been given to them. Empirical evidence shows that igneous tivity is accompanied by the evolution of water vapor, but what is the source of this water? is :

a. Newly synthesized water, formed when magmatic temperature drops below the critical mperature of water at the depth of origin ?

b. Connate or other trapped, deep-lying water which is vaporized and driven out a head a rising igneous mass ?

c. Meteoric water which has circulated to considerable depth and is being driven out by neous activity ?

d. Water of composition or crystallization which is liberated as rock-minerals are digested melted by an igneous mass ?

e. Or did all water originate at some stage in earth history, with no further synthesis during ologic time ?

None of these problems is simple, and much that has been written about them is largely onjectural. If juvenile water is being generated continuously, a worldwide average rate of about) cubic miles per year (relatively, a minuscule quantity) through geologic time would account or all the water known to exist. But is it actually being generated at all ? By what means ?

The question is not merely academic. If water originated by igneous action in the earth, ought also to originate by similar action in the moon (8.22) perhaps in planets like Venus and Iars. Obviously, no free water can exist on the moon's surface, but at shallow depth it may be resent as ground water or ground ice. Though highly mineralized, such water might be obtained nd beneficiated by space explorers at less cost than by transpiration of water from earth or ynthesis of water from its elements.

. Distribution of Water in the Environment (9)

Nace (U.S. Geol. Survey Circular 415) made a crude estimate of the distribution of the vorld supply of water. No similar estimate has been published for the several continents or ountries of the world. The smaller the region the less accurate the estimated values would e and the more specific the measurements that would be needed.

A sample distribution sheet for the United States (table 1) illustrates the general idea. imilar estimates might be roughed out for each continent or country.

. Hydrology of Type Areas (Systems) (11)

Operation of hydrologic cycle differs in differing situations and some of these differences re very marked. It would be instructive, for example, to develop area studies (systems analyses) or what might be called type areas — areas which are distinctive in their combinations of atitude, climate, topography, geology, soil, and vegetation. Examples are as follows :

1. The closed arid basin (Death Valley; Salton Sea; Caspian Basin; Dead Sea). A possible variation : Closed basin in a steppe environment (Red Desert, Wyoming, U.S.A.)

TABLE 1

Approximate distribution of water in the United States (48 conterminous States)

	Area (sq. mi.)	Vol. (cu. mi).	Ann. circ. (million-ac-ft (yr))	Detention period (yr
Frozen water				
Glaciers	200	16	1.3	40
Ground ice (seasonal only)				
Liquid water				
Fresh-water lakes *a*)	61,000	4,500	150	100
Salt lakes	2,600	14	4.6	10
Average in stream channels	——	12	1.500	.0[illegible]
Ground water				
Shallow	3,000,000	15,000	250	200
Deep	3,000,000	15,000	5	10,000
Soil moisture (3-ft root zone)	3,000,000	150	2,500	0.2
Gaseous water				
Atmosphere	3,000,000	45	5,000	.0[illegible]

a) U.S. portion of Great Lakes only.

2. The open arid basin (Sahara Desert; Murray River basin; Colorado Desert; Lake Ch basin).
3. Humid and subhumid basins in various latitudes.
4. Ocean islands — various kinds and various latitudes (Hawaiian Islands; Azor Puerto Rico or others of the West Indies; Samoa, others).
5. Mediterranean islands (Minorca; Sicily; Crete).
6. Glaciated areas (Iceland; Ellesmere Land; Greenland; Antarctica).
7. Permafrost areas (Alaska; Siberia).

The list could be added to almost endlessly, but these examples indicate the potential sco of subject. The basic question : Can universal truths be distilled that will permit useful inferenc about the hydrology of areas on the basis of known factors in the environment but witho specific hydrologic data. Knowing the latitude, climate, and general setting of an area, f example, what can be deduced about its hydrology from aerial photographs ? We might c this photohydrology.

D. Effects of Climatic Changes on Vegetation and Runoff (2.31)

Recorded history of North America is too short to allow definitive conclusions abo effects of climatic change. Much may be learned about historic changes from studies in dendr chronology, pollen analysis, archeological investigations, and other fields. Long human habit tion and historic records extending backward into history, however, make Palestine and oth

Middle Eastern countries exceptionally promising areas for study. The work of Evenari and others already has disclosed much that was learned once and then forgotten about means for adjustment of man to his environment in an arid climate.

E. Studies to Test Theories of Glaciation (2.32)

Continental glaciation is a recurrent phenomenon, the causes of which remain unknown. Numerous explanatory theories have been advanced, but none has received general acceptance. Ewing and Dunnen have proposed a new theory. Other writers have proposed means to alter the climate of the northern circumpolar region by remodeling submarine topography in certain areas to change the regiments of certain ocean currents. This proposal unwarrantedly implies thorough knowledge about factors that control the Arctic climate. Theories should be tested by appropriate studies, of which the following are example topics: Measurement of ocean currents in places like the Bering and Davis Straits; studies of the heat balance and heat transport by air and water; studies of the water budget; and many other topics. Concurrent studies would be needed in oceanography and meteorology.

F. Chemistry of Precipitation (1.424)

Water is only one of the variable constituents of the atmosphere. Others are chemicals, gases, and entrained solids. (foreign and natural). The role of the atmosphere in the chemical balance of the earth is, in effect, an aspect of geochemistry.

The composition of river waters may be a fair index of the rate of weathering, but some evidence indicates that the water composition is biased. That is, a correction is necessary for cyclic salts. These salts are continually brought in by air masses from ocean areas, rained down on the land, and returned to the sea in rivers. Other constituents and fission products also should be considered, for other purposes.

Before firm recommendations could be made for the study of rain chemistry, the following matters should be considered:

a. To what extent would information in existing depositories fill the basic-data need?

b. Some international work in meteorology is already underway. Erik Eriksson, of Sweden, for example, has established the start of a hemispheric network of meteorological stations. *Tellus* periodically contains reports on this network. Reportedly, a new meteorological network in Russia and Siberia is being activated through the Swedish International Meteorological Institute. Does this work include chemistry of precipitation?

c. The International Association of Scientific Hydrology has in progress an informal program of international cooperation to obtain samples of water from 65 principal rivers of the world. A more formal program may move faster and yield more coverage, but the data now coming in should be fully studied as an aid to programming. This work should be coordinated with the collection of rain samples for chemical analysis.

d. Many Federal and State agencies may have substantial repositories of data.

e. Stations for collecting new data should be keyed, so far as possible to existing hydrologic and meteorologic networks. The very great amount of streamflow, water chemistry, and precipitation data already available for North America, Scandinavia, and certain other parts of the world ought to permit clarification of some relations between several parameters of the hydrologic cycle.

f. In the selection of new or established stations, should one base these on (1) a grid system or (2) on location with respect to air-mass movements?

g. What sort of quantitative information actually could be developed from a large mass of data? In order to make quantitative measurements of chemical characteristics, it is necessary to establish boundaries. Can this be done, for example, with large air masses? Would it be better to select a relatively few primary hydrologic stations in principal river basins, representing headwater, mid-basin, and downstream areas, keyed in to general air-mass movements?

h. After initial sampling, would it be feasible to apply analytical and indirect-correlation techniques in order to avoid accumulation of masses of data which might be indigestible?

i. Sheer size of the chemical analysis job might be a limiting factor on what could be accomplished in a rain-chemistry project.

G. Effects of Man on the Environment (15)

The outstanding action by man on the physical environment in the United States and some other countries has been exploitation and indiscriminate use, rather than wise management. A few examples are available of wise management and use (= conservation) as an expression of enlightened self-interest. Timber farming in the Pacific Northwest and a few other areas is an example. Government agencies have carried on extensive programs for conservation of soil and water, but by and large these have been based on empirical data, not on scientific principle. Among scientists the suspicion is strong that some of these practices may do more harm than good, in the long run, or that their effects are quite different from those intended. There is a very real deficiency in knowledge about the effects of man, for good or ill, on his own environment.

Many areas are available for case studies in the United States, but more is needed than examinations of what has happened in "horrible-example" situations. Studies are needed on what has been accomplished in areas where man has been an intruder for a long time and where adjustment with the environment has been or is being achieved. Some of the best opportunities for studies are available overseas. Examples of what seem to be suitable studies are the following:

1. Succession of vegetation where the original timber cover was eradicated. An example is the well-established historic effects of timber eradication in the Scottish Highlands, followed by the encroachment of bracken fens. After deforestation, what natural processes brought on the subsequent changes, and why?

2. Forest and river control and management. In places like Germany and Switzerland control and management seem to have been highly successful. What principles have been used and followed to achieve this success?

3. Desert water management. In the Negev Desert, according to findings of M. Evenari and colleagues, methods were in use in biblical times whereby man was able to practice agriculture under conditions that tasked his ingenuity to the utmost. These areas are now uninhabited. Much can be learned about affecting the environment to improve its habitability, as well as avoiding deleterious effects.

4. Variability of supply in semiarid regions. Semiarid regions occupy a very large area on the continents. A crucial problem in these areas is variability in the water supply. What are possible ways to improve and stabilize water supply in semiarid areas? Some of the ways must include manmade or man-induced changes in the environment.

5. Effect of development of urban-industrial complexes on hydrologic processes. These great complexes must have profound effects on local hydrologic processes. Little qualitative information is available, however, about runoff and floods; low flow; sediment production; ground-water recharge; effects of yard watering; contamination and pollution; and many other factors.

H. Comparative Hydrology and Sedimentology

Much remains to be learned about the hydrologic and sediment-movement characteristics of streams. So many variables are involved that the effects of each are difficult to discriminate. The rate of advancement in knowledge and understanding probably could be accelerated by comparative studies of watersheds in similar climatic zones in various parts of the world. Many kinds of studies could be enumerated, but it seems sufficient here merely to suggest a few topics in this general field.

Empirical evidence indicates that there are marked differences in the distribution of sediment sizes about the mean size of material deposited by streams, depending on whether the mean size is large or small. It would be useful to obtain samples of river sediments from various rivers and continents and to determine whether there is some universal relation between stream hydraulics and sediment movement.

Another kind of study concerns chemical quality. Are there universal chemical characteristics of water in relation to specific kinds of climate, topography, and lithology?

In the United States extensive studies have been made of flood hydrology and the recurrence of floods of specific magnitude. Is the recurrence interval of the mean annual flood, for example, similar on other continents?

Extensive chains of reservoirs on essentially clear streams like the Columbia River may be expected to operate for a long time with very little loss of storage space. A stream system like that of the Missouri River basin, however, is entirely different. The aim of dam construction may be to achieve essentially complete regulation. But if the reservoirs silt up in 50 to 75 years, the end result is a completely unregulated basin. What principles can be worked to forestall this unwanted effect? Are surface reservoirs the best or only method to obtain a regulated water supply?

I. Comparative Morphology and Evolution of Streams and Canals

The causes of meandering and other stream patterns, of entrenchment and aggradation, and of other features of stream and canal morphology and evolution are but poorly known. Comparative studies should be made of the influences of climate, vegetation, topography, geology, and other factors. These would improve understanding of channel and valley morphology and of the dynamics of channel and valley evolution. Understanding will be more and more important as man increases his changes in the environment and as river regiments change more and more.

J. Water Quality in Relation to Public Health

International cooperation should be stressed as a means for advancing science and thereby improving the ability of foreign countries to develop their own resources and advance their own well being. The World Health Organization of the United Nations has concerned itself mostly with the medical aspects of health. However, the biological and chemical quality of water supplies is closely related to problems of human health. WHO has begun to give more attention to the conservation and protection of water supplies from the public-health standpoint. The scope of the public-health program might well be enlarged to give more attention to studies of water resources and the preservation of water quality in relation to public health.

An international program of cooperation in hydrology might well stress the economic and sociologic benefits to be derived from applied hydrology in the development of water resources and in the protection of public health. It is not suggested that the program should become directly involved in public-health problems as such. Rather, it should demonstrate the application of hydrologic and hydrogeochemical principles to prevent or control pollution and contamination of waters.

Components of earth's water system

Following is a working outline which identifies principal components, factors, and processes in the earth's water system. The outline is sufficiently complete to provide a framework for delineating or classifying typical subjects, but is not necessarily comprehensive. There is no implication that an international program would or could cover the entire range of topics, or even that any one topic would be "wrapped up". Hydrologists have generations of work before them.

The outline does, however, provide a basis for classifying and selecting many feasible programs. It also includes topics about which much information is available but widely scattered or confused. Summary reports on these are badly needed.

It may seem inconsistent to include subjects like "Effects of man on the environment" in an outline of "components, factors, and processes in the earth's water system". Many people regard the works of man as "artificial", which they are, etymologically. No one would deny, however, that the so-called biological cycle impinges upon and influences the hydrologic cycle. Man is a part of the biosphere, and the writer believes that it is "natural" for man to do whatever he does. He distinguishes "effects of man" rather than "effects of clams" simply because man, by himself, now exercises a significant influence on the hydrologic cycle in appreciable areas of the earth.

TABLE 2 (*)

Topical inventory: Components, factors, and processes in the earth's water system

1. *Comparative dimensions and characteristics of principal earth features.*

1.1 Ocean basins (1) — form, size, depth, distribution, and other characteristics.
- 1.11 Principal ocean currents — circulation pattern; other pertinent data.
- 1.12 Density and thermal stratification; turnover rates and processes.
- 1.13 Chemical composition and balance.
  - 1.131 Gross chemistry and regimen; salt, carbon dioxide and other balances; others.
  - 1.132 Trace constituents and their regimens; radiometric properties and balances.
- 1.14 Sedimentology — terrigenous debris; precipitates; organic debris.
- 1.15 Gulf seas; mediterranean basins; rift-basin seas; traits; fjords.
- 1.16 Frozen seas; ice floes; icebergs.
- 1.17 Ocean levels — seasonal and long-term trends; synoptic differences and anomalies.

1.2 Continents (2) — form, size, altitude, distribution.
- 1.21 Major surface features that affect or control the water system.
- 1.22 Peculiar features — peninsular and isthmian areas.
- 1.23 Major subsurface features that affect or control the water system.
- 1.24 The zone of fracture.
  - 1.241 Principal lithologic terranes — limestone; shale; sandstone; intrusive igneous; volcanic; various kinds of metamorphic; others.
  - 1.242 Relative volume of porous sedimentary and igneous masses an nonporous crystalline masses.
- 1.25 The zone of flowage — brief treatment to establish a "bottom" to the water system.

1.3 Oceania (2) — size, form, and distribution of principal islands and archipelagos.

1.4 Atmosphere (3) — height, density, composition.
- 1.41 Principal circulation patterns that influence the hydrologic cycle.
- 1.42 Other pertinent atmospheric processes.
  - 1.421 Carbon dioxide balance.
  - 1.422 Chemical transportation — salt transportation, etc.
  - 1.423 Physical transportation.
  - 1.424 Rainout and fallout; chemistry of precipitation.

(*) See footnotes at end of table.

Summary: Interplay of major earth features to produce the observed net result — the global and continental hydrologic cycles.

1 Operative processes (4) — evaporation, ablation, sublimation, transpiration, dew fall, runoff, infiltration, percolation, underflow, effluent seepage, glacial transport.

2 World circulation of water. (4)

2.21 Circulation of water: Ocean ⇌ atmosphere; atmosphere ⇌ land; land ⇌ oceans.
2.22 Sources of precipitation — maritime; continental.

3 Climatic changes an their effects on the hydrologic cycle.

2.31 Effects on vegetation, recharge and runoff.
2.32 Glaciation and "ice ages" — causes and effects.

Chemical classes of water — fresh; brackish; saline, including concentrated brine; acidic and basic; mineralized; sodium bicarbonate, and others.

1 Hydrogeologic interpretation of chemical classes of natural water.

Environmental classes of water. (5)

.1 Marine
.2 Inland seas and lakes
.3 Streams
.4 Ice caps, glaciers, and snow fields
.5 Soil moisture
.6 Vadose water
.7 Ground water
.8 Connate water
.9 Atmospheric moisture
.10 Organic water (in plants and animals)

Availability classes of water. (5)

5.1 Precipitation
5.2 Runoff
5.3 Soil moisture
5.4 Ground water
5.5 Desalted water
5.6 Imported and exported water

6. *Properties of water — vapor, liquid and solid.*

6.1 Physical
6.2 Chemical
6.3 Optical
6.4 Molecular structure and behavior

7. *Forms and occurrences of water.*

7.1 Free water: Water that is available to participate in the hydrologic cycle (vapor, liquid, and solid).

7.2 Chemically combined water: Water of composition; water of crystallization.
    7.21 Amount of such water.
7.3 Trapped water: Mineral inclusions; so-called connate ("fossil") water; ice and sno ground ice.
    7.31 Special properties of these waters.

8. *Genetic classes of water.*

8.1 Meteoric and juvenile (magmatic).
8.2 Ultimate origin of earth's water.
8.3 Theories and likely processes.
8.4 Translation to extra-terrestrial possibilities (Example: Does the moon contain ground wa or ground ice?)

9. *Gross global water budget: Quantitative average and seasonal distribution of water.*

9.1 Oceanic water, including sea ice and shelf ice.
9.2 Atmospheric moisture.
9.3 Continental water.
    9.31 Ponds, marshes, lakes, streams, and inland seas.
        9.311 Saline water
        9.312 Fresh water
    9.32 Glaciers, ice caps, and snowfields.
    9.33 Soil moisture.
    9.34 Vadose water.
    9.35 Ground water.
    9.36 Ground ice (permafrost)
    9.37 Organic: In plants and animals.
9.4 Residence (detention) times of water in the ocean, in inland seas and lakes, in streams, glaciers and icecaps, in soil, and in the zone of saturation.
9.5 Hydrochemical cycle and balance: Salts and other substances; chemical erosion.
9.6 Sedimentation regimes; physical erosion.
9.7 Seasonal and long-term shifts in the distribution of water.
    9.71 Effects on sea levels.
    9.72 Effects on earth's rotation.
    9.73 State of icecaps, glaciers, and snowfield; fluctuations in relation to climate.
    9.74 Wet and dry seasons and periods.
    9.75 Glacial and interglacial periods.

10. *The hydrologic cycle: Operation.*

10.1 Evaporation.
    10.11 Oceanic — open sea; gulf areas; ice areas.
    10.12 Continental.
        10.121 Streams, reservoirs, and lakes.
        10.122 Snowfields, glaciers, icecaps.
        10.123 Soil moisture.
        10.124 Fumaroles, geysers, volcanoes.
10.2 Transpiration: Plant and animal
10.3 Runoff.
    10.31 Overland and channeled.
    10.32 Low flow; flood flow.
    10.33 Glacier discharge; sapping of icecaps.

10.4 Infiltration and percolation.
10.5 Underflow; effluent seepage; base flow.
10.6 Dynamics of the cycle — sources and amounts of energy.

11. *Variations of the hydrologic cycle: Type-area studies.*

11.1 Humid areas — tropical, temperate, north temperate.
11.2 Arid (desert) areas — equatorial, temperate, arctic, etc.
11.3 Tundras — high altitude; low altitude.
11.4 Glaciated areas.

12. *Uses of water.*

12.1 Direct uses: Simple inventory of uses for agriculture, industry, public supply, farm and domestic, navigation, power generation, dilution of waste, recreation.
12.2 Indirect uses: Soil-moisture depletion.
12.3 Water balance sheet.
 12.31 Total use.
 12.32 Unused balance.
 12.33 Recoverable residue.

13. *Technologic possibilities for increasing the effective supply of water.*

13.1 More efficient use and reuse.
 13.11 Increase and conservation of soil moisture.
 13.12 Reduction of wasteful applications.
 13.13 Control of low-order use.
 13.14 Control of contamination.
 13.15 Control of temperature.
13.2 Evaporation suppression.
13.3 Evaporation stimulation: Technology is deficient.
13.4 Salt-water beneficiation: Technology is adequate; energy demand is the limiting factor.
13.5 Weather modification: Largely a problem of technology (most of the needed energy is free)
13.6 Long-range development and use plans.
 13.61 Scientific basis for water management.
  13.611 Law of diminishing returns: water storage, dependable flow, and other aspects.
  13.612 Use of underground reservoirs — for storage; for reserve; for equalization; for other purposes.

14. *Economics and energy requirements for water development.*

14.1 Sufficiency of available water for any potential demand.
 14.12 The problem: Not supply of water, but source and supply of energy for beneficiation and delivery of water.
 14.13 Technology: Adequacy to meet the problem.
 14.14 Energy demand: The critical problem adequacy to meet the problem.
  14.141 Energy demand for conversion and transport of large volumes of water.
  14.142 Energy available: Fossil fuels; hydropower; atomic energy; solar energy; aeolian energy; others.

15. *Effects of man on the environment.*

15.1 Effects of water withdrawals.
15.2 Effects of water use: Chemical effects; contamination and pollution; stream and ground-water regimens; temperature changes; sediment regimens.
15.3 Effects of land use.
  15.31 Land use and land-use changes (irrigation; dry farming; urbanization; artificial levees; channel dredging; drainage of wet lands; deforestation; reforestation, grazing; others).
15.4 Many others (too numerous for specification in this brief outline).

(1) Hydrologic topics would impinge somewhat on the long-term world program of oceanography. The treatment here, however, would emphasize hydrologic and sedimentation aspects of oceanography, with special emphasis on the role of the ocean in the hydrologic cycle, the chemical cycle, and the disposition of terrigenous clastic sediments.

(2) Continents and Oceania would be treated in terms of gross physical geography, with emphasis on features that have significant effects on global and continental aspects of the hydrologic cycle.

(3) Atmospheric studies would impinge on programs in meteorology, climatology, and atmospheric physics. The emphasis would be on the atmosphere in relation to the hydrologic cycle and its role in the chemical and sediment aspects of hydrology.

(4) Item 2.1 would concern the processes as such. Item 2.2 would concern the effects of the processes.

(5) Items 4 and 5 include topics that superficially resemble topics that occur elsewhere in the outline. Under these items, however, we are concerned with the classification of water on the basis of its environment and availability.

RELATING SEASONAL AND WATER YEAR RUNOFF (1)

R. A. WORK (2) (U.S.A.)

INTRODUCTION

In developing a useful water supply forecast scheme the water user's needs are paramount. These needs differ for various specific purposes. Any generalization as to type of forecast most often needed is not possible. It can be said, however, that in nearly all cases the users' need is for forecasts of runoff yet to come. Whether forecasts of runoff are for amounts to be available for gravity diversion for irrigation, municipal, industrial, or domestic use; or for inflow to reservoirs, where a decision is made if all prospective runoff should be held, or much allowed to pass through in order to retain space for flood control, the need is mainly to foresee the runoff or the inflows of the future. That which has occurred has either been impounded, has been used, or has wasted to the sea or to salty inland lakes. Whatever its disposition, such water belongs almost entirely to the past. It belongs to the future only in such degree as recent past records or events provide operating criteria essential to current or future decisions.

The author's objective is to emphasize the water users' basic need for the best possible forecasts of events yet to occur, and to point out that blending of past and future runoff in any forecasts requires meticulous treatment to avoid misunderstanding in the interpretation and application of such a forecast.

TYPES OF FORECASTS

One type of forecast is described as for the "water year". Such a forecast may be issued any time during the 12 months beginning October 1 and terminating September 30. The runoff "forecast" is that of the full 12 months. If the forecast be issued January 1, it includes runoff, either estimated or measured, which occurred in the preceding three months, plus that which is predicted for the next nine months. As of April 1, such a forecast, in reference to time, is one-half historical and one-half predicted.

Such forecasts, as with seasonal forecasts, which usually are for April-September, are expressed in terms of "acre-feet" and also as "percent of average". Expression of a numerical forecast as "percent of average" offers a convenient and generally used method of conveying to irrigators, to water managers, and to the public, advance knowledge as to whether the future runoff will be about the same as, or greater or less than the average flow of the past. The reader may assume the forecast as one completely of the future by the term "forecast".

RELATIONSHIP OF SEASONAL AND WATER YEAR FLOW

For some rivers there appears to be no fixed or predictable relationship between runoff in the first part of the water year (the snow accumulation period, October-March) and that in the later part (the period of snowmelt and principal water need, April-September). As an example, note the annual relationship of these volumes for each of 37 years for Rogue River above Prospect, Oregon, as shown in Figure 1.

(1) Paper presented at Pacific Northwest Regional Group meeting, American Geophysical Union, held at Portland, Oregon, October 31-November 1, 1961.

(2) Head, Snow Survey and Water Forecast Unit, Soil Conservation Service, U.S. Department of Agriculture.

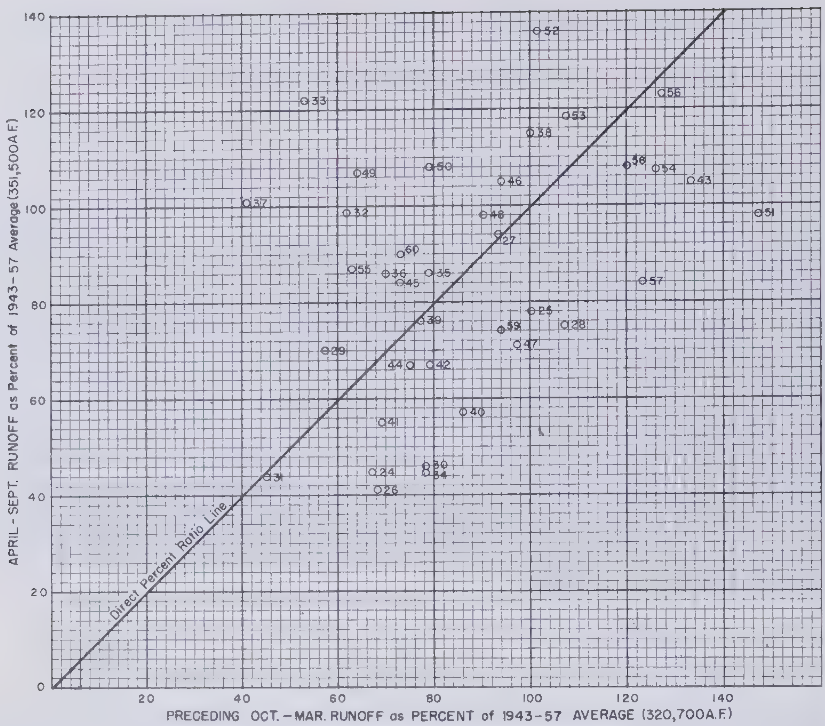

FIGURE I Rogue River Above Prospect, Oregon

Runoff for the "water year" and that of its concluding critical water-use months (Apri August or April-September of the year) likewise is not dependably related in all streams. T illustrate this statement let us consider several streams of differing watershed characteristic Figure 2, for instance, shows in a bar chart the relationship or, one might better say, lack c reliable relationship between seasonal and annual runoff for the Silvies River in Orego This is an agricultural stream, lacking storage. Late spring and early summer flows are use to wild-flood the valley meadow land.

Figure 3, shows in a different fashion, the relationship between April-September runo (expressed as percent of the 1943-57 average) and the water year runoff (expressed also as pe cent of its 1943-57 average) for Rogue River above Prospect, Oregon. Reservoir storage c any tributary of Rogue River is only minor. Flows of this river are important for irrigatio power generation, and recreation. Water shortages, requiring advance planning to meet su deficiencies, can occur if the total seasonal flow is much below 75 percent average. The peri of average is 1943-57, recently adopted by all federal agencies in Columbia Basin for su studies.

Inspection of Figure 3 shows that seasonal runoff can be below average in years whe water year runoff is above average. Conversely, in years when water year runoff is belo average, that for the irrigation season can be above average. It is incorrect to reason that the annual runoff is above average the seasonal runoff should be likewise, or vice-versa. A pinpointed in the chart, when the annual runoff was about 90 percent average, the season runoff was 75 and 122 percent average, and could have ranged from 70 to 123 percent averag

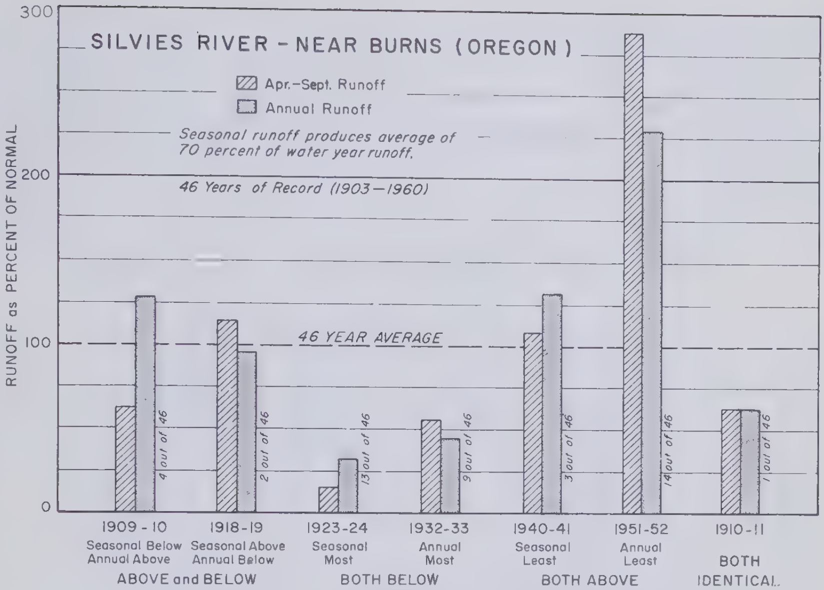

FIGURE 2 This chart shows seven possible combinations of the relationship of water year runoff to the seasonal runoff for April-September for 46 years of record

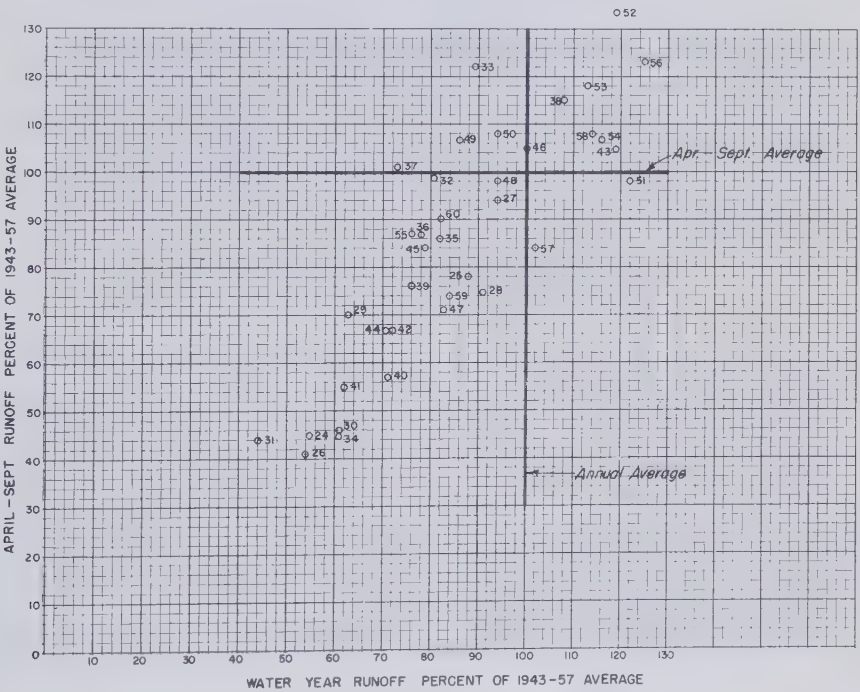

FIGURE 3 Rogue River Above Prospect, Oregon

There is a general tendency on snowmelt rivers, in those water years which show delo
average flow, for the seasonal flow to be lower in proportion to average than for the annu
flow to so be. Conversely, in water years of above average flow the tendency is for the season
flow to be higher in proportion to average than for the annual. The reason is sound. In yea
of heavy seasonal flow, which is a normal reflection of heavy snowpacks, a greater than avera
part of the total annual flow is produced after the spring snowmelt begins. The converse
often the case in years of light seasonal flow. This can be demonstrated by a simple diagram
in Figure 4 for Rogue River.

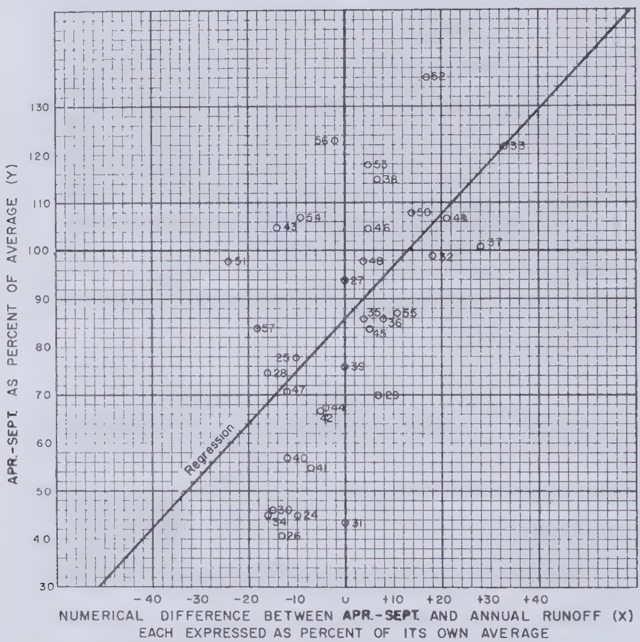

FIGURE 4 Rogue River Above Prospect, Oregon
Showing trend for seasonal flows less than annual in seasons of below normal flow, when each is expressed as percent of its own normal, and the converse in years of above normal seasonal flow.

In Figure 4 the seasonal runoff (April-September), expressed each year as a percenta
of the 1943-57 average, is plotted on the vertical scale. Each ordinate plotting is position
on the horizontal scale by expressing the horizontal plotting as numerical difference ea
year between seasonal runoff and water year runoff (each being expressed as percent of
own average for 1943-57 period). When the seasonal percentage is less than the annual perce
tage the plotting is to the left of the vertical zero difference line. When the seasonal percent
greater than the annual, the plotting is to the right, or plus side of the zero difference li
If there were a perfect relationship between seasonal and annual runoff, the plottings wou
all be on, or close to, the zero axis.

This chart shows for Rogue River a pronounced tendency, in years of above avera
seasonal runoff, for the seasonal runoff to be more greatly above average than for the ann
runoff to be above average.

The chart likewise shows that in years of below average seasonal runoff there is a definite tendency for the seasonal runoff to be more greatly below average than for the annual runoff to so be, where each is expressed as percent of its own average.

The shotgun plotting pattern, however, clearly evidences that this situation is anything but hard-and-fast. In consequence, the mean relationship for this stream cannot be used to indicate the exact relationship between seasonal and water-year runoff for any individual year.

To further illustrate need for discretion in comparing seasonal forecasts based on snow surveys with those for the "water year", Figure 5 demonstrates the differences with respect to relationship of seasonal and water-year runoff between several individual rivers over the West.

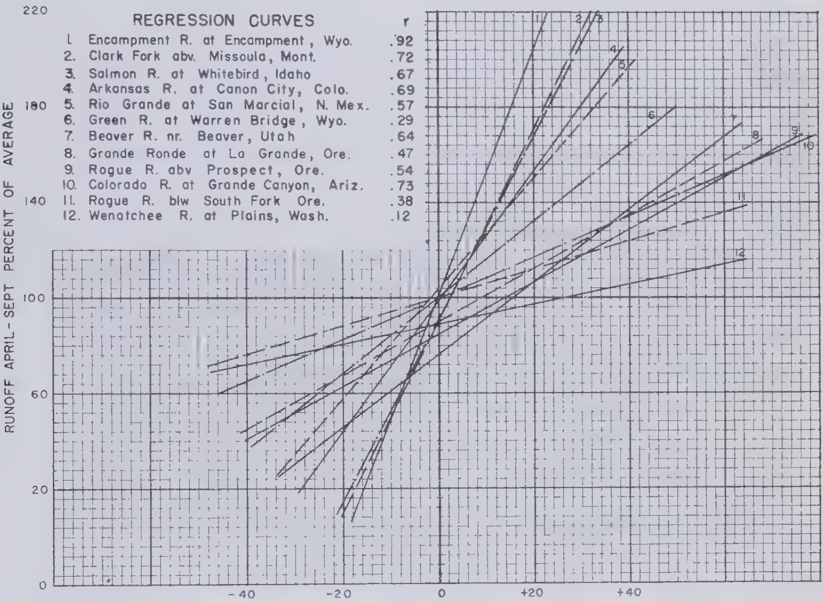

FIGURE 5 Numerical difference between Apr.-Sept runoff and annual runoff when each is expressed as percent of its own average.

The slope differences of the relationship lines are due in part to watershed characteristics and in part to climatic differences which include varying proportions of the total annual precipitation which occurs as snow.

Conclusion

There is a lack of a sharply predictable relationship between the seasonal runoff and that for the water year in the basins cited. These differing values arise from differing time periods of precipitation; are affected by different loss factors, such as groundwater carryover, winter temperatures, etc., and therefore, can and should be compared for the sole purpose only of estimating the difference between them as sometimes being representative of runoff which already has passed into history.

Recommendation

Part of the difficulty due to the differences between seasonal and water year forecasts would be removed if the differing periods of forecast were specifically defined in all technical or news releases by the various agencies preparing and releasing such forecasts. For instance, traditional forecasts of seasonal flow by the Soil Conservation Service and its numerous cooperating agencies, should not only be plainly described as seasonal or for the irrigation season, but should be defined specifically as for April-September, for July-September, May-September, March-June, or for the exact time period encompassed by the specific forecast. The Service will re-double its efforts in this respect.

PREMIÈRE CONFÉRENCE INTERAFRICAINE DE LA COMMISSION DE COOPÉRATION TECHNIQUE EN AFRIQUE AU SUD DU SAHARA SUR L'HYDROLOGIE

NAIROBI 16-25 JANVIER 1961

J. RODIER (*France*)

Cette conférence a réuni environ 130 participants délégués par presque la totalité des États d'Afrique au Sud du Sahara. Les différents domaines de l'hydrologie étaient assez bien représentés puisqu'on comptait des spécialistes d'hydrologie superficielle, des hydrogéologues, des géophysiciens. Seuls les pédologues n'étaient pas représentés, ils auraient pourtant été fort utiles dans les discussions concernant l'érosion et les problèmes d'infiltration.

Deux réunions préliminaires, l'une à BUKAVU, l'autre à YAOUNDE, avaient permis une préparation assez poussée de cette conférence. D'autre part, les hydrologues africains se connaissent depuis longtemps, de sorte que l'ambiance de la Conférence a été très détendue et très amicale ce qui a contribué certainement à simplifier les discussions.

L'ordre du jour comportait l'examen de questions d'ordre général traitées en sessions pleinières et de problèmes techniques ou scientifiques.

Ont été discutés en sessions pleinières, les sujets suivants :

1) Importance des études hydrologiques dans le développement d'un pays.

2) Hydrologie des principaux bassins fluviaux de l'Afrique au Sud du SAHARA — État d'avancement des études.

3) Effets des méthodes d'utilisation des sols sur les ressources en eau.

4) Organisation de la Coopération interafricaine dans le domaine de l'hydrologie et dans les domaines connexes.

En sessions techniques, ont été examinés des problèmes particuliers se rapportant aux questions suivantes :

I — *Hydrométéorologie* :

1) Précipitations
2) Évaporation et transpiration
3) Radiations

II — *Hydrologie des eaux superficielles* :

1) Étude des crues et de l'écoulement des rivières
2) Étude des transports solides
3) Dégradation des rivières en zone aride
4) Hydrologie des lacs et marécages

III — *Bassins expérimentaux en Afrique* :

IV — *Hydrologie des eaux souterraines*

Cent trente communications ont été présentées sur ces sujets. La synthèse en a été faite dans 16 rapports généraux.

En ce qui concerne l'étude des précipitations, les rapporteurs ont insisté plus particulièr- ment sur les méthodes d'estimation de la hauteur de précipitation moyenne sur une superfic donnée, sur le diagramme des averses élémentaires : les tornades de l'Afrique de l'Ouest s sont avérées très voisines des orages de l'Afrique Australe et de l'Afrique Orientale; on souligné la nécessité d'établir des courbes de hauteur-superficie-durée pour les précipitatio orageuses maximum probables, ou plus simplement des courbes intensités-durée-fréquenc pour des périodes inférieures à 24 heures.

Les appareils de mesure de l'évaporation tendent à se normaliser dans l'ensemble c l'Afrique. L'étude de l'évaporation par l'emploi de distillomètre et l'étude de la radiation o fait de gros progrès. Le rapport entre évapotranspiration sur couvert forestier et évaporatio sur nappe d'eau libre a fait l'objet d'importants échanges d'informations. Des conclusio assez peu optimistes résultent des communications présentées sur l'efficacité des couvertur monomoléculaires des réservoirs pour la lutte contre l'évaporation.

L'étude de l'écoulement des rivières a mis en évidence qu'il était bien difficile de normalise les formes de publication des données et notamment les annuaires hydrologiques. Les méthode utilisées pour l'estimation des débits de crue de faible fréquence varient considérablement d'u bout à l'autre de l'Afrique en relation avec le caractère particulier des divers régimes hydro logiques. Les services hydrologiques rencontrent les mêmes difficultés pour l'exploitation d leurs réseaux. On a beaucoup insiste sur la nécessité de concilier, dans l'établissement jud cieux des réseaux, l'obtention des données *sûres* avec les faibles moyens financiers disponible

Les rapporteurs ont mis en garde des hydrologues africains contre l'emploi aveugle d formules de transports solides, sans tenir compte des conditions locales.

La dégradation hydrographique des cours d'eau sahéliens et subdésertiques a fait l'obj d'échanges de vue intéressants sur la création de points d'eau dans ces régions.

Les confrontations des études sur bassins expérimentaux dans l'Afrique Occidentale e l'Afrique Orientale ont montré que, dans le premier ensemble de territoires, on recherchai surtout à calculer les crues maxima sur petits bassins et, dans le second ensemble où, dan le cas général, les ressources en eau sont beaucoup plus réduites, on cherche, comme en Europe à déterminer le mode de couverture végétale qui affecte le moins les ressources en eau. O note, par ailleurs, que si les conditions physiques sont équivalentes, les bassins d'Afriqu Orientale présentent des débits spécifiques de crues tout à fait comparables à ceux de l'Afriqu de l'Ouest.

Tous les spécialistes des eaux souterraines ont insisté sur le nécessité d'étudier l'alimentatio des nappes avant de les mettre en exploitation.

Pour l'Afrique Orientale et l'Afrique Australe, un fichier a été présenté concernant l'avance ment des études sur les divers bassins fluviaux. On va tenter de compléter cet ensemble d façon à obtenir un fichier général pour l'ensemble des bassins au Sud du Sahara.

La coopération interafricaine a fait l'objet de longues discussions et de nombreuses recom mandations ont été prises à ce sujet : Il est prévu que des listes de spécialistes s'occupan d'hydrologie seront mises au point État par État, que la bibliographie africaine en hydrologi sera complétée année par année à partir de 1959. Ce travail sera effectué dans le cadre d réseau de correspondants hydrologues de la C.C.T.A.

La formation du personnel a beaucoup intéressé les participants à cette conférence e il a été convenu que des stages pour agents techniques seraient organisés en Afrique à bre délai.

Des réunions régionales seront prochainement convoquées pour deux premiers ensembles

1) Le bassin du NIGER

2) Les pays riverains du TCHAD

Cette coordination s'effectuera en liaison avec les organisations spécialisées des Nation Unies, plus particulièrement la F.A.O. et le Centre de Mise en Valeur des Ressources Hydrau liques, dont les représentants ont participé de façon très active et très efficace aux discussion sur ces matières.

Une réunion de tous les correspondants s'est tenue à la fin de la conférence, sous la présidence du coordinateur interafricain, réunion au cours de laquelle ont été examinés les détails pratiques concernant la mise en œuvre des diverses mesures de coopération mentionnées plus haut.

Deux excursions ont été organisées au cours de la Conférence. La première à permis de visiter une station expérimentale d'irrigation à proximité des contreforts du Mont Kenya.

La seconde, qui a duré 3 jours, a conduit les participants aux bassins expérimentaux de Kimakia, au voisinage des Monts Aberdare et de Kericho, en pleine zone de culture du thé, ainsi qu'aux ouvrages alimentant Nairobi en eau potable. Plusieurs projets d'irrigation ont été présentés dans le «Rift Valley» et au voisinage du Lac Victoria.

Cette tournée ajoutait à un très grand intérêt technique les agréments de splendides paysages de l'Afrique Centrale et de l'hospitalité des plus sympathiques des autorités du Kenya.

FLOOD FREQUENCIES AS RELATED TO LAND USE (1)

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U.S. Geological Survey, Washington 25, D. C.

Results of recently completed study (Schneider and Ayer, 1961) indicate that progressiv changes in forest cover on a basin causes substantial changes in flood-peak magnitudes. Th flood magnitude-frequency relation based on observed data during the period of change considerably different from one which might have been developed had not changes occurre in the forest cover.

The Study Areas

Shackham Brook near Truxton, New York drains 3.12 square miles. Prior to an intensiv reforestation program, land use in the basin consisted of about 25 percent deciduous wood lots and 75 percent pasture and cropland. During 1931 to 1933 about 56 percent of the basi was planted with coniferous trees consisting mostly of Norway spruce and red pine. Two-yea old seedlings were planted on abandoned farmlands which the State had acquired for refores tation. At the time of planting, this land was covered with weeds and brush which had develope on idle cropland and pastures. Streamflow records are available from 1932.

In 1938, the Albright Creek basin was selected as a control area against which change i streamflow of Shackham Brook would be measured. Albright Creek at East Homer, New Yor drains 7.08 square miles. Land use in the basin consists of about 20 percent second-growt deciduous woodland and about 80 percent open pasture and cropland and has not change appreciably since the establishment of the area as a control. On the other hand, the refoeste portions of the Shackham Brook area have developed into relatively dense coniferous fores with trees generally over 25 feet high which form a complete canopy cover over the refoeste areas.

Occurrence of Annual Peaks

The annual peak discharge is the maximum discharge occurring during the hydrologi year. Because of the generally low streamflow conditions in central New York State eac autumn, the period October 1 to September 30 was selected as the hydrologic year. Mos annual peaks in Central New York occur during late winter or spring as the result of genera rainfall accompanied by snowmelt. However, severe thunderstorms in June and July occa sionally yield sufficient runoff to produce the annual peak. In the Shackham Brook area fifteen of the annual peaks occurred during the winter and early spring period, and four durin the June-July period.

The Change in Annual Peaks

A multiple-regression time-trend analysis using the annual peak discharges for Shackhar Brook and Albright Creek for the period 1939 to 1957 was made to determine possible change in the relationships between peaks of the two areas. The regression equation was computed a

$$\log S = 0.853 + 0.633 \log A - 0.019\, T \qquad (1$$

(1) Publication authorized by the Director, U.S. Geological Survey.

in which S is the annual peak discharge of Shackham Brook in cfs, A is the concurrent annual peak discharge of Albright Creek in cfs, and T is the position of the peak in a chronological yearly sequence beginning with $T = 1$ for 1939 water year. This relationship is shown graphically in figure 1. The coefficient of T was determined to be highly significant by statistical

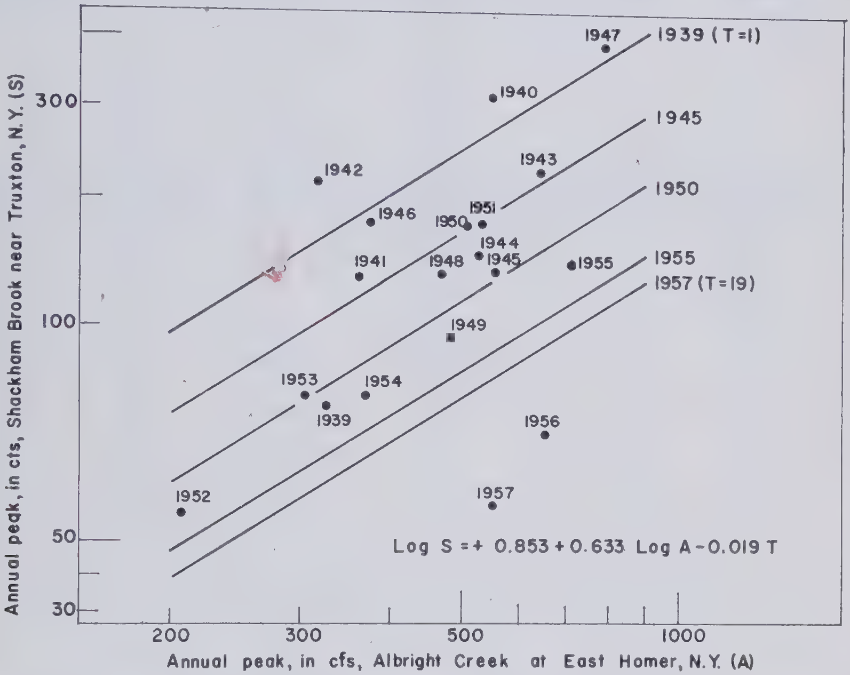

Fig. 1 — Change with time in the relation between annual flood peaks from two basins.

tests (Ezekiel, 1950, p. 321-325) indicating a progressive reduction of peak discharges on Shackham Brook between 1939 and 1957 from those which would have occurred had there been no time trend. This reduction amounts to 55 percent for the period of record, or an average cumulative reduction of 2.9 percent per year. The reduction is attributed to the gradual increase in infiltration capacities of the soils in the reforested parts of Shackham Brook watershed as well as increased interception by the conifers.

The time-trend factor of $-0.019\,T$ in equation 1 can be used to adjust the observed peak discharges (Q_0) on Shackham Brook to obtain the estimated peak discharges (Q_E) which would have occurred under land-use conditions prior to 1939. Adjusted peaks were obtained from the relationships

$$\log Q_E = \log Q_0 + 0.019\,T \qquad (2)$$

The adjusted peaks and the observed peaks each were arrayed by magnitude and the associated recurrence interval was assigned to each arrayed position, as shown in table 1. Figure 2 shows the frequency plotting of these data based on the theory of extreme-value probabilities (Gumbel, 1958). Note the upper position of the adjusted frequency curve indicating an increase of 50 percent at the 2.33-year recurrence interval and 32 percent at the 20-year recurrence interval. The difference in the slopes of the two curves is negligible in this case because there is no signi-

TABLE 1

Data on annual peak discharges ofShackham Brook near Truxton, N. Y.

Year	Observed peak discharge	Adjustment in cfs	Adjustment peak discharge Q_E	Arrayed Q_0	Arrayed Q_E	Recurrence interval in years
1939	155	5	160	487	614	20
1940	416	24	440	416	440	10
1941	234	20	254	328	393	6.67
1942	278	32	310	319	383	5
1943	328	48	376	278	376	4
1944	250	43	293	278	369	3.33
1945	236	48	284	274	335	2.86
1946	319	74	393	250	310	2.50
1947	487	127	614	236	304	2.22
1948	236	68	304	236	293	2.00
1949	319	62	255	234	284	1.82
1950	274	95	369	224	255	1.66
1951	278	105	383	193	254	1.54
1952	110	45	155	161	236	1.43
1953	161	70	231	161	231	1.32
1954	161	75	236	155	217	1.25
1955	224	111	335	142	175	1.18
1956	142	75	217	113	160	1.11
1957	113	62	175	110	155	1.05

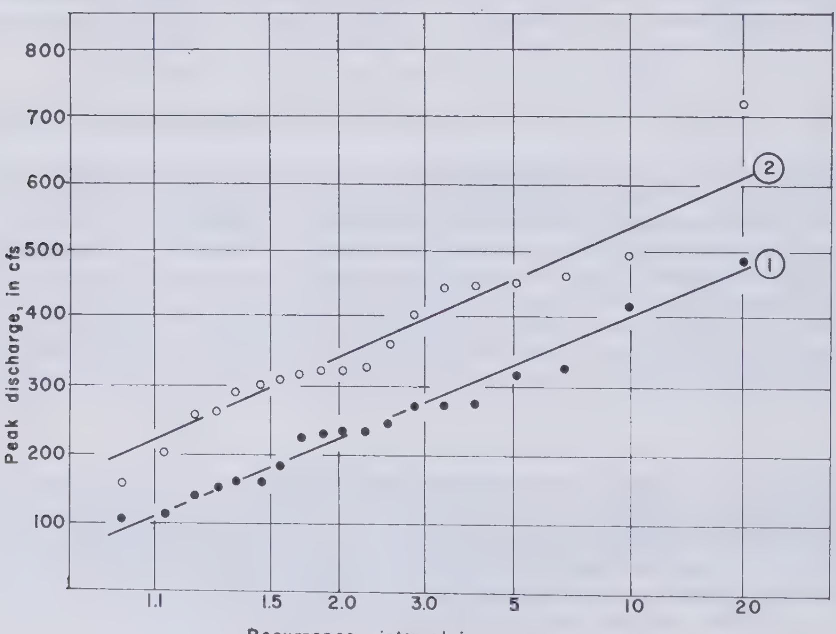

Fig. 2 — Cumulative frequency curves of annual peak discharges for Shackham Brook near Truxton, N.Y., (1) as defined by records over a period of changing forest cover, and (2) as computed for a constant condition of negligible forest cover.

icant correlation between the magnitude of the peak and its chronological position. If this correlation had existed — for example, if most of the higher peaks tended to group into either the early or late part of the study period — the upper curve in figure 2 would not be parallel to the lower curve, but would tend to either converge or diverge.

Land use is an important factor in hydrologic relationships among areas. As shown in the above study for the Shackham Brook watershed, moderate or severe changes in land use may significantly affect flood magnitude-frequency relationships.

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HYDROGÉOLOGIE DE LA RÉGION CENTRALE DE L'ASIE MINEURE

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RÉSUMÉ

Cette étude se rapporte en premier lieu au conditions géographiques de la région centrale de l'Asi Mineure ainsi qu'à sa structure géologique. Elle est limitée au Nord par les chaînes pontiques et a Sud par les Taurus. Elle est constituée par un groupe de zones orogéniques qui tendent à s'écarter le uns des autres par l'intercalation des massifs anciens. Dans ce complexe les dépôts mésosoiques e tertiaires de différentes zones orogéniques (faciés flysch) différent de ceux des parties intermédiaire (faciés calcaire). La période entre l'Eocène supérieur et le Miocène est représentée par une série clas tique gypsifère très épaisse. Les terrains néogènes lacustres occupent la plus grande partie des plateau internes en remplissant une multitudes de bassins tantöt isolés, tantöt reliés les uns aux autres. L'aspec d'ensemble du pays est celui d'un plateau à vallées encaissées : l'altitude du plateau est d'environ 1000 à 1200 m. Le fond des vallées est de 100 à 200 m plus bas.

Comme l'avenir économique de cette région, en grande partie steppique semi-désertique, dépen surtout des ressources en eau, dans une seconde partie de l'étude, il a été essayé de résumer ce qu'o sait sur la circulation des eaux souterraines et d'évaluer approximativement le volume d'eau utulisable

L'Analyse des Cartes géologiques les plus récentes d'Anatolie permet de distinguer plu sieurs unités tectoniques dans ce pays. Ce sont : les plis bordiers tout à fait au Sud, les Taurus l'Anatolie Centrale et enfin les chaînes Pontiques. En Anatolie Centrale, il s'agit d'un group de divers systèmes orogéniques analogues qui, en Anatolie orientale et occidentale se réunissen pour former une seule unité, tandis que dans l'intérieur du pays, l'intercalation des massif anciens forcent les diverses zones orogéniques à s'écarter les unes des autres. Les massifs ancien comportent des schistes cristallins, du Permo-carbonifère et des roches intrusives. Le Méso zoïque des zones orogéniques de l'Anatolie Centrale diffère de celui des parties intermédiaires Dans les zones orogéniques, il est représenté par le Jurassique et le Crétacé à faciès flysch à intercalation des radiolarites et de calcaires massifs. Toutes ces zones orogéniques sont riche en roches vertes dont l'intrusion a probablement débuté au Crétacé inférieur. Dans quelque zones intermédiaires, les sédiments à faciès calcaires de Trias et de Jurassique affleurent. Le Tertiaire dans l'Anatolie Centrale a un développement caractéristique. L'Eocène, débutan par le Paléocène, est souvent représenté par le flysch. La période entre le Lutétien supérieu et l'Oligocène sont représentés par une série clastique typique renfermant du gypse. Le Miocène dont les dépôts en partie marin à l'Est, se développe plus à l'Ouest sous forme de dépôt lacustres occupant des grandes superficies. Ici le Pliocène est parfois lagunaire.

Des épanchements d'Andésite ont eu lieu à partir de l'Eocène. Après la sédimentatio de la Série Gypsifère, commença une nouvelle extrusion de magmas basaltiques et andésitique qui a probablement duré jusqu'aux temps historiques.

L'aridité de l'Anatolie Centrale s'affirme progressivement depuis le littoral de la Méditer rannée, de la Mer Egée et de la Mer Noire, favorisée par les barrières montagneuses qui inter ceptent l'humidité et forment un écran l'empêchant d'accéder à l'arrière-pays.

Les formes dominantes dans l'Anatolie Centrale entre Ankara-Eskisehir, que nous voulon exposer ici, sont les modelés de plateaux où les grandes surfaces d'aspect uniforme, ordinaire ment à des altitudes 1100 à 1200 m, se distinguent nettement des reliefs qui les dominent Au dessous des plateaux on voit tantôt des larges depressions, tantôt des vallées encaissées Cette région aplanie, qu'on peut suivre depuis Ankara jusqu'à l'W de Eskisehir, a une remar quable continuité, abstraction faite des reliefs montagneux qui les entourent et d'un certai nombre de grandes depressions enclavées dans les plateaux. Les plateaux en question peuven être représentés comme une vaste péneplaine, modelée avant le Néogène et déformée depui

cette période; elle est tantôt masquée sous les remplissages néogènes, et tantôt elle est visible dans les intervalles entre les dépressions. A l'époque de Miocène la région était largement occupée par des lacs d'eau douce qui s'étendaient dans divers bassins. Les matériaux provenant des rides émergées, ont été déposés dans ces lacs en forme de conglomérats interstratifiés avec d'autres sédiments lacustres.

Les dépressions qui se séparent des plateaux, généralement de forme ovale ou circulaire, sont les OVA s d'Anatolie Centrale.

Plusieurs ovas sont enclavés entre les plateaux autour d'Ankara et d'Eskisehir. Ce sont :

Autour d'Ankara : Mürted ovasi, Çubuk ovasi, Ankara, Etimesut ovasi, Maliköy ovasi.

Autour d'Eskisehir : Inönü ovasi, Eskisehir ovasi, Alpu ovasi, Bassin de Parsuk, Bassin du Haut Sakarya.

La formation des Ovas, qui sont des éléments morphologiques très caractéristiques de l'Anatolie Centrale a été longtemps discutée. On les a considéré comme des bassins d'érosion alternativement remplis et vidés suivant les oscillations du niveau de base. D'autres les ont considérés comme des vallées longitudinales en relation avec la structure tectonique. Philippson les considérait comme des bassins tectoniques dans le genre de Graben; tandis que W. Penck les définissait comme des régions synclinales d'une structure de plis de fond dirigé E-W.

Les observations plus récentes ont clairement montré que les Ovas en question sont sûrement une conséquence de mouvements tectoniques. Avant le remblaiement par des dépôts lacustres et alluviaux, le fond de la cuvette a été déjà affaissé. Sur les bordures des Ovas, on voit souvent des calcaires lacustres miocènes disloqués (failles ou flexures). Il y a donc une phase de dislocation post-miocène, au cours de laquelle les régions les plus abaissées seraient devenues des Ovas.

Certaines failles affectant le Néogène sont relativement anciennes. Sur les bords des Ovas autour d'Ankara et d'Eskişehir, les failles sont nivelées par des plateaux à 900-1000 m d'altitude, mais les régions occupées actuellement par ces dépressions peuvent provenir d'affaissements plus récents ayant déformé la surface topographique des plateaux. Dans le Ova d'Inönü, par exemple, les coulées basaltiques affleurent sur le plateau et descendent jusqu'au dessous des alluvions de l'Ova; or ces coulées sont plus récentes que le Néogène lacustre et elles ne sont pas recouvertes sur les plateaux par d'autres terrains. Si leur abaissement sous le Ova est bien dû à une flexure, l'affaissement de la dépression est plus récent que le modelé des plateaux. Ainsi le modelé des Ovas, avant l'alluvionnement serait d'origine tectonique et ne proviendrait pas de l'érosion.

Climat

Le climat des plateaux entre Ankara-Eskiehşir peut être caractérisé avec une certaine précision d'après les observations faites à des stations météorologiques d'Eskişehir (800 m), d'Ankara (891 m), de Sivrihisar (1280 m), de Polatli (87,500 m).

La température moyenne, pour chaque mois et pour toute l'année, calculée d'après les observations faites pendant 30 ans de 1930-1960 sont :

	Janv.	Fev.	Mars	Avril	Mai	Juin	
Pour Eskişehir	0.25	1.05	1.6	11.4	16.2	19.2	
Pour Ankara	—1	1.06	5.04	11.07	16.70	19.5	
	Juillet	Août	Sept.	Oct.	Nov.	Déc.	Moyenne
Pour Eskişehir	24.2	21.8	17.1	11.2	6.7	9.5	11.7
Pour Ankara	22.5	22.8	18.7	12.4	7.16	2.6	11.5

Les résultats sont peu différents pour les deux stations.

L'amplitude annuelle, calculée d'après les moyennes du mois le plus chaud et du mois le plus froid est de 28.7° pour Eskişehir et de 26.2° pour Ankara.

La moyenne des maximas absolus pour la période 1930-1960 a varié
à Eskişehir entre 35 et 37.8
à Ankara entre 35 et 38.
On compte en général 150 jours d'été où la température s'élève au dessus de 25°.
Le minimum absolu a varié de la manière suivante :

	1931	*1935*	*1948*	*1950*	*1955*	*1958*
Eskişehir	— 16.7	— 16	— 26.3	— 23.8	— 10.1	— 13.3
Ankara			— 17.5	— 24.4	— 8.3	— 10.3

Les grands froids sont d'ailleurs habituellement d'assez courte durée. En janvier 1950, tandis que les minimas absolus s'abaissaient à — 24.4 à Ankara, à — 26.3 à Eskişehir, les minimas moyens étaient respectivement de — 3.2 et 3.8. L'amplitude journalière, différence entre les températures maxima et minima de chaque jour est d'environ

	En Janvier	*En Juillet-Août*
à Eskişehir	3.7°	28.0°
à Ankara	0.25°	25.3°

Précipitation

Les nombreuses observations faites sur la hauteur des précipitations donnent des résultats importants. Les moyennes annuelles sont les suivantes :

à Eskişehir (pour la période 1930-1960)			363 m/m	
à Ankara	»	»	» 357	»
à Sivrihisar	»	»	» 382	»
à Polatlı	»	»	» 340	»

Il faut surtout considérer les différences entre les hauteurs mensuelles, soit dans une même année, soit dans des années différentes. En choisissant deux années, l'une particulièrement sèche, l'autre généralement humide, on obtient les chiffres suivants :

Une période de forte précipitation se place donc au printemps (Mars, Avril, Mai).

L'évaporation est considérable; d'après les mesures faites aux évaporimètres de l'Observatoire d'Ankara, la hauteur d'eau évaporée annuellement varie entre 1.50 et 2.10. On peut admettre une moyenne de 1.80 m.

Le rapport de la hauteur des précipitations mesurées en m/m, à la température moyenne d'après les chiffres indiqués ci-dessus serait : pour Eskişehir et Ankara 31. D'après la formule de E. de Martonne l'indice d'aridité serait pour Eskişehir 16.7 et pour Ankara 16.6 (climat semi-aride).

Par suite des caractères du climat semi-aride, la désagrégation des roches est dûe aux variations brusques de la température et surtout aux alternances de gel et de dégel. L'éclatement des roches perméables et fissurées par la congélation suivant l'imbibition est très fréquent. Les manteaux de désagrégation superficielle ont une grande importance. La végétation étant rare, il y a peu de ruissellement sur la roche à nu, et l'eau provenant des pluies et de la fonte des neiges s'infiltre rapidement dans les terrains fissurés ou meubles. Par suite de la fréquence des pluies d'orage, l'entraînement de ces matériaux sur les pentes aux fonds des vallées et des Ovas, s'effectue facilement; il est rare que les fonds des vallées montrent la roche vive; au

dessous des altitudes moyennes des plateaux, l'épaisseur des alluvions est couramment de l'ordre de grandeur de 25-30 m.

1956 (Année sèche)	J.	F.	Ms.	Av.	M.	Jn.
Eskişehir	27.9	66.3	18.3	7.4	28.6	23.0
Ankara	36.8	82.0	25.5	16.0	29.7	12.5
1958 (Année humide)						
Eskişehir	76.1	10.8	53.8	41.5	17.4	47.8
Ankara	36.2	22.3	89.8	39.8	28.4	62.0
Moyenne mensuelle calculée pour une longue période :						
Eskişehir	39.6	36.0	46.8	39.9	44.0	33.2
Ankara	30.8	36.0	47.0	40.0	44.6	33.3

1956 (Année sèche)	Jt.	At.	S.	O.	N.	D.	Total
Eskişehir	0.0	0.0	0.5	3.8	15.0	35.0	215.8
Ankara	0.5	0.0	8.1	4.9	5.0	27.5	247.5
1958 (Année humide)							
Eskişehir	18.1	0.1	41.1	22.4	9.3	39.7	402.6
Ankara	3.1	1.5	20.8	28.2	7.7	46.6	404.4
Moyenne mensuelle calculée pour une longue période :							
Eskişehir	11.2	4.2	30.5	25.1	19.8	34.4	
Ankara	10.1	8.2	30.6	25.1	18.8	34.1	

D'après les données résumées ci-dessus, il s'agit pour les ovas en question, d'un pays semi-aride dont l'avenir économique dépend surtout de ses ressources en eau souterraine. Nous essayerons de résumer ce qu'on sait actuellement sur les eaux souterraines et de déterminer les meilleures méthodes de leur utilisation.

Esquisse géologique

Le caractère fondamental de la géologie de cette région est l'extension considérable des formations néogènes lacustres. Elles affleurent sur plus de 2/3 de la superficie et sont presque partout présents à une faible profondeur. Sur la roche ante-néogène, s'est déposé la série lacustre essentiellement conglomératique, gréseuse et calcaire qui a probablement recouvert tous les plateaux actuels; mais a été partiellement érodé là où le soubassement a été exhaussé par les mouvements tectoniques, et conservé dans les dépressions. Des produits volcaniques (tufs et laves) sont souvent intercalés dans la série lacustre.

Région d'Ankara

Le plateau d'Ankara est dominé à l'E, par le massif andésitique de l'Hüseyin Gazi (1400 m); au SE, par le Paléozoïque de l'Elmadağ dont les larges croupes s'élèvent à plus de 1800 m. Au NE, par Idrisdağ (1900) et au N par les hauteurs mésozoïques et tertiaires de Memlik et de Bağlum (1300-1450 m). Au-dessous du plateau se séparent les vallées nettement encaissées et les larges dépressions des ovas dont l'altitude moyenne est de 900-1000 m. Sur le versant NW de l'Elmadağ, les eaux vont au Sakarya, tandis que sur le versant SE, elles vont au Kizil Irmak. Au delà du large col de Lalabeli (1200 m), on franchit le faîte hydrographique entre Sakarya et Kizil Irmak. La région d'Ankara est drainée vers la Mer Noire (faisceau de Sakarya) par plusieurs petits cours d'eau (Çubuk Çay, Kayaş deresi, ince Su, Ova Suyu) qui se réunissent près d'Ankara et forment alors l'Ankara Çayi. Celui-ci sort de l'Ova par un défilé étroit. L'Ankara Ovasi, est une dépression de 25 km de long et 10-12 km de large. Les sédiments et volcanites du Néogène jouent le rôle essentiel dans sa structure. Sur le bord méridional, des conglomérats à cailloux peu roulés, empâtés dans un ciment calcaire, reposent sur les terrains anciens. Les matériaux des conglomérats provenant des terrains anciens s'enfoncent vers le N sous des marnes brunes ou blanches qui sont sans doute contemporaines des calcaires lacustres.

Les calcaires et marnes lacustres s'étendent au N jusqu'à la vallée d'Ankara Çayi, tandis que la surface de l'ova est couverte des argiles pliocènes et des cailloutis pliopléistocènes. Abstractions faites des alluvions, les terrains tertiaires ont une disposition générale synclinale, les plongements étant, dans l'ensemble vers les régions centrales ou axiales de l'Ova. Cette disposition est compliquée sur les bords de l'Ova par des failles et des flexures visibles en d'assez nombreux points des limites des terrains tertiaires; tandis que en d'autres points, la bordure du synclinal ne montre pas d'accidents particuliers.

Le défilé du Çubukçay, en amont d'Ankara se termine à environ 17 km au N de la ville; la vallée s'élargit alors, dans les terrains néogènes de Çubuk Ova. Situé au N du massif andésitique d'Ankara et à l'E du plateau de Bağlum, le Çubuk ova a une forme presque circulaire dont le diamètre atteint 20-25 km. Il est drainé par le Çubukçay. Les eaux de cette rivière sont retenues en amont d'un barrage établi sur le défilé à sa sortie de l'Ova. Le plan de la nappe d'eau dans le retenu est à 920 m. (*)

Dans le Çubuk ova le tertiaire est représenté par des conglomérats épais, comprenant en particulier des cailloux roulés de laves et reposant sur les roches éruptives.

Les couches de conglomérats sont faiblement inclinées vers le N. Mais plus au N on observe localement des plongements très accentués jusqu'à la verticale correspondant sans doute à une ligne de flexure dirigée E-W.

Une autre dépression dirigée de NE à SW s'étend au N de la vallée d'Ankara Çay : c'est le Murted ova dont la longueur est plus de 40 km et la largeur de 10 km. Il est drainé par le Ova Çay. L'entrée et la sortie de ce cours d'eau de l'Ova se fait par des vallées transversales très étroites. Le passage du plateau à la plaine se fait par des pentes assez douces, tandis que l'encaissement de la vallée, marqué par un relief convexe, est apparent dans le Ova.

Ici encore, le Néogène lacustre est dominant dans la structure de l'Ova. Abstraction faite des calcaires, grès et marnes, les dépôts de tufs volcaniques, subaquatiques jouent un rôle assez important. La série est toujours couronnée par des calcaires lacustres. Ces derniers sont quelquefois silicifiés ou bien transformés en silex. Le plateau à l'W de Murted ova est tapissé de ces silexes qui ont parfois une épaisseur de 100 m.

Toutes ces formations ont été affectées par les mouvements tectoniques les plus récents. Malgré la disposition tabulaire des couches, des flexures ou failles ne sont pas rares sur les bords.

(*) La retenue a une capacité de 13,5 million de m^3 et le bassin d'alimentation 700 km^2 de superficie. Le débit moyen annuel est de 27.000.000 m^3.

Région d'Eskisehir

A l'W d'Eskişehir, le Néogène occupe la dépression d'Inônü Ovası où il descend au-dessous du fond de la vallée de Sarisu (afluent du Porsuk), c'est-à-dire à moins de 800 m d'altitude. Cette zone du Néogène se rétrécit vers l'W et ensuite elle se termine. Plus à l'W les vallons entament directement le soubassement metamorphique. Le Néogène d'Inönü ovasi, affaissé par rapport à celui du plateau, est limité vers le S par une ligne régulière qu'on peut suivre depuis Eskisehir et qui est une faille ou flexure. Une source thermale jaillit sur cette ligne.

La dépression suivie par le Sarisu puis par le Porsuk en aval d'Eskişehir est une zone d'affaissement tectonique où le Néogène est conservé sous les alluvions, tandis que les rides dominant le Ova sont généralement formées des terrains anciens. Les accidents tectoniques affectant le Néogène sont parfois des failles nettes avec miroirs de friction.

A l'E d'Eskişehir, les grands plateaux steppiques dont l'altitude moyenne est d'environ 1100 m sont couverts du Néogène dont l'allure générale est presque tabulaire. Cependant le soubassement anténéogène est souvent atteint a faible profondeur. Ce sont des marbres, des radiolarites en lits interstratifiés, traversés par des roches vertes serpentinisées; ils sont tous fortement plissés. On voit sur le plateau, dominant de 200 m la large vallée de Porsuk, quelques placages de conglomérats néogènes. Mais le soubassement anteneógène affleure presque partout. Le plateau s'abaisse doucement vers la vallée de Porsuk. A une altitude d'environ 850 m on passe des serpentines ou d'autres roches au Néogène qui comprend des conglomérats, des marnes et des calcaires lacustres; tous ces terrains sont redressés près du contact avec les serpentines, contact qui se fait suivant une flexure.

En allant encore vers l'E, on est dans le bassin de Porsuk proprement dit, où les plateaux se développent dominés par des hauteurs éparses, parfois encore groupées en chaîne allongée. Le Néogène de la plaine alluviale est en grande partie marqué par le recouvrement quaternaire alluvial et par des dépôts plus récents. A ces alluvions peuvent être rattachées latéralement celles des grandes cônes de déjection qui bordent la dépression. Le remblayage des grandes plaines de Porsuk et du Haut Sakarya a probablement commencé dès le Quaternaire de même que les formations des cônes de déjection.

Le bassin de Porsuk est limité au S, d'abord par une étroite ride dirigée de NW au SE, et qui se développe davantage vers le SE. C'est le massif de Karakaya-Sivrihisar. Le soubassement de cette zone médiane qui domine aussi vers le S, le bassin du Haut Sakarya est constitué par des terrains métamorphiques traversés par des aiguilles de granit. Le massif est également recouvert par endroit par des terrains néogènes.

La dépression du Haut-Sakarya, si l'on fait abstraction des vallées qui l'entament apparaît surtout comme un vaste piémont rocheux des hauteurs de la zone médiane de Karakaya-Sivrihisar et de la ride de Karatepe-Emirdağ. Cette vaste plaine où le Néogène lacustre occupe des grandes surfaces est couverte d'un manteau d'alluvions dont l'épaisseur diminue à mesure qu'on s'éloigne des bordures; elle représente une surface d'érosion très évoluée. Le bord de la plaine alluviale montre des failles affectant le Néogène; mais on n'a pas là de preuves d'une flexure récente des surfaces topographiques aplanies.

Hydrogéologie

Nous avons vu qu'autour d'Ankara et Eskişehir existent généralement des terrains très fissurés et perméables, comme calcaires marbres, calcaires lacustre, conglomérats-grès, tufs volcaniques. Lorsque ces roches sont à nu, il y a peu de ruissellement, l'eau s'infiltre rapidement. Mais on devrait surtout insister sur la grande extension et la grande épaisseur du manteau superficiel, meuble et perméable, provenant des matériaux volcaniques et des terrains néogènes. Ceux-ci occupent actuellement les grandes dépressions; mais ils s'étendaient primitivement sur la presque totalité des plateaux. Ce manteau perméable a souvent une épaisseur de plusieurs mètres sur les plateaux; et au-dessous des altitudes moyennes des plateaux l'épaisseur des alluvions du fond des vallées peut atteindre 25-30 m.

Grâce à l'existence de ces grandes épaisseurs de terrains meubles une partie importante de l'eau de pluie pénètre rapidement dans le sol. Quand le sol est imperméable, le ruissellement est très rapide sur les pentes fortes et les eaux, surtout d'orages brusques arrivent vite aux fonds alluviaux où elles s'infiltrent.

Dans toute la région du plateau Ankara-Eskişehir en dehors des grands cours d'eau (Sakarya, Porsuk), il n'y a presque pas de rivières permanentes. Toutes les petites vallées sont normalement sèches; mais il est facile de comprendre que l'écoulement souterrain a une grande importance et la circulation intra-alluvial pour les cours d'eau temporaires ou pour les vallées sèches est loin d'être négligeable.

Les mesures directes de débit de ces eaux souterraines sont presque impossibles. Pour les vallées sèches des cours d'eau de mêmes conditions d'altitude, de pentes et de nature de soubassement d'alluvions, sur le flanc N d'Elmadağ au S d'Ankara, le débit minimum de la nappe d'eau qui s'écoule sous les alluvions a été déterminé indirectement et vérifié par les captages des vallées sèches dont le soubassement est schisteux et imperméable et non faillé. Ce débit minimum est à peu près 1-2 litres par seconde et par km^2 de bassin d'alimentation.

Il est donc facile, pour chaque vallée sèche, d'évaluer approximativement, d'après la surface du bassin d'alimentation, le volume d'eau que l'on peut obtenir pour des irrigations (celle-ci s'effectuant au printemps en période de débit au moins moyen) ou pour des adductions d'eau potable.

Il y a lieu d'ajouter que, pour ces vallées sèches, la pente longitudinale est d'au moins 10‰; il suffit donc d'une longueur de galeries souterraines d'environ 1 km pour amener au niveau du sol, sur un territoire d'irrigation, l'eau d'une nappe souterraine située à 10 m de profondeur.

Le soutirage par gravité pourrait être appliqué dans toutes ces vallées et même dans les grandes. A Ankara Çayi, par exemple, dont la pente est d'environ 3‰. Ici la nappe d'eau souterraine est en été à 3-4 m seulement. On pourrait donc irriguer le territoire de l'ova au moyen de galeries souterraines dont la longueur ne dépasserait guère 1 km.

Des captations d'eaux souterraines dans les alluvions existent depuis des temps historiques aux environs d'Ankara.

Les documents historiques et archéologiques donnent des renseignements précieux pour de pareilles captations dans d'autres régions d'Anatolie Centrale et permettent de savoir comment les anciennes étaient alimentées en eau. Par exemple la ville de Kayseri est actuellement alimentée en eau potable par une galerie souterraine de 5 km, construite au Xème siècle par les Selçuks, collectant une série d'autres galeries captantes et filtrantes, fournissant régulièrement 150 l/sec. Ces galeries sont creusées dans des cônes de déjection et des tufs volcaniques, très poreux, laissant suinter l'eau. Ces roches ont une énorme importance comme roche-magasin, il suffirait même d'étudier et de développer ces méthodes pour augmenter leur possibilité d'exploitation.

On a trouvé à une dizaine de km d'Ankara et à 6-8 m au-dessous de la plaine de Kayaş, dans la vallée sèche de Kosunlar descendant d'Elmadağ, une large galerie souterraine, dite «galerie romaine» à l'altitude (925 m), permettant d'amener l'eau des alluvions par gravité sur les pentes des collines d'Ankara (900 m). Cette galerie obstruée jusqu'en 1927, a été réparée et utilisée jusqu'en 1933 pour l'alimentation d'Ankara.

Le fond de la vallée est à 960 m; les sondages préliminaires ont traversé des alluvions perméables, sables et cailloutis, les lits d'argile n'ayant qu'une importance secondaire; à une dizaine de mètres de profondeur, on a atteint le soubassement des schistes imperméables. Une conduite forcé à la base des alluvions a pu fournir en été un débit minimum de 30 litres à la seconde. La surface d'alimentation correspondant est de 20-25 km^2.

Plus tard 4 puits de 25 m de profondeur ont été creusés jusqu'à la base des alluvions et ont fournit 50-80 l/sec. Lorsqu'on descend au-dessous de l'altitude moyenne des plateaux, l'épaisseur des alluvions devient considérable et les eaux qui étaient libres à des altitudes supérieures deviennent dès lors souterraines.

Toutes les vallées sèches de la base des massifs montagneux peuvent donc être aménagées en captant les eaux souterraines et en les amenant par gravité à des altitudes voulues.

Ces alluvions des vallées sont donc particulièrement intéressantes par suite de leur relativement grande perméabilité. Les sables et surtout les graviers des vallées d'une épaisseur variable entre 10-15 m reposant sur les limons quaternaires, constituent d'excellents reservoirs que les rivières peuvent alimenter. Ces graviers forment généralement une couche assez peu homogène et s'étendent sur des grandes distances. Les nappes contenues dans les alluvions sont exploitées par les puits qui jalonnent les différentes vallées autour d'Ankara. Le tableau ci-dessous donne pour quelques-unes de ces vallées le nombre de puits existant, le débit qu'ils fournissent et l'épaisseur des alluvions :

	Nombre de puits	Épaisseur des alluvions	Débit total en l/sec	
Vallée de Kosunlar	4	25 m	50 - 80	
Vallée de Kayaş	13	22 - 29 m	130 - 230	débit
Vallée d'Ince Su	11	30 - 32	150	moyen
Vallée de Çubuk	11	20 - 35	175	
Vallon de Dikmen	1	30	1 - 2	
Vallon de Kavaklıdere	1	40	0.30	
Vallée d'Ankaraçay	2	16	40	
Total			610 l/sec	

soit environ 50.000 tonnes par jour et en saison sèche. Ces captages récoltent surtout les eaux absorbées par les alluvions.

Les principales nappes aquifères plus profondes sont contenues dans le Néogène affleurant sur les plateaux et constituant généralement le soubassement des Ovas. La nappe est alimentée par le eaux de pluie qui ruissellent sur ces roches et s'infiltrent. La succession des couches néogènes présentant des alternances de marnes, de sables et conglomérats ainsi que des tufs volcaniques réalise une série de réservoirs aquifères artésiens en profondeur dont les exploitations de ressources sont souvent limitées par la finesse des sables. Il faut cependant remarquer que ces formations sont sujets de changements de faciès, soit en direction verticale et soit en direction horizontale. Ainsi dans la partie occidentale de l'Ankara Ovasi les forages préliminaires ont atteint l'aquifère :

à 88 - 96 m	dans les sables fins néogènes et ont fournis	3 l/sec
à 80 - 100 m	dans les sables et cailloutis et ont fournis	15 l/sec
à 68 - 76 m	dans les sables argileux et ont fournis	1 l/sec
à 54 - 84 m	dans les gros cailloux et ont fournis	20 l/sec.

Dans l'Ankara Ovası d'assez nombreux puits artésiens y prennent leur eau. Comme les sables et cailloutis s'étendent sur de notables étendues, il est certain qu'il constitue le meilleur niveau aquifère du Néogène.

Dans la région d'Eskişehir abstraction faite des nappes dans les alluvions dont l'épaisseur est de 12-16 m les forages exécutés dans le Néogène ont montré la présence de 2 nappes superposées, l'une à 59-62 m, l'autre à 96-98 m de profondeur et fournisssant chacune 10 l/sec.

Les sondages d'Alpu ovasi, à l'E d'Eskişehir, ont montré dans le Néogène plusieurs nappes

superposées, dont les niveaux statiques sont d'autant plus haut que l'aquifère est plus profonde :

+ 4.50m pour la formation de surface
+ 2.80m pour l'aquifère située entre 19 et 40 m
+ 1.50m pour l'aquifère située à 60 m
+ 1.20m pour l'aquifère située entre 65 et 70 m
+ 0.55m pour l'aquifère située à 88 m.

Leur débit est de 10 lt/sec.

Un peu plus à l'E, dans le bassin de Porsuk la première nappe artésienne a été atteinte à 45 m de profondeur avec un débit de 10 l/sec. Ces nappes paraissent n'avoir aucune issue ni vers la mer ni vers un bassin d'évaporation apparente.

Plus à l'E encore, dans le bassin du Porsuk, le Néogène lacustre se termine par une épaisse série lagunaire appartenant au Pliocène. Elle comprend de bas en haut des marnes, du gypse, des sables et graviers, des argiles bleues avec des lits du sel gemme, de nouveau du gypse et de l'argile. Un forage exécuté dans cette série à Ilören, profond de 175 m, n'a pas fourni de l'eau utilisable.

Il faudrait remarquer cependant qu'une grande partie des eaux des plateaux se perd dans les gouffres et fissures du Néogène calcaire. Parfois elles réapparaissent, après un écoulement souterrain, aux sources importantes au bord des Ovas. Ainsi à l'W d'İnönü ovasi, la zone néogène se rétrécit entre Kandilli et Bozalan. Ces deux villages, distants de 10 km, sont dans le même ova dirigé vers l'E-SE. A Kandilli les eaux s'écoulent vers le Sarisu, tandis que à Bozalan, où une forte source jaillit, elles s'écoulent vers le Karasu de Bilecik. Malgré une plus grande superficie du bassin d'alimentation à Sarisu, le débit de Karasu est très supérieur à celui de Sarisu : les eaux de ce dernier se perdent dans les fissures de calcaires entre les deux bassins pour réapparaître à Bozalan.

Les nappes des séries sédimentaires plus anciennes que le Néogène, n'ont pas été étudiées jusqu'à présent au point de vue hydrogéologique et n'ont pas été reconnues en profondeur. Le primaire ancien ne présente guère de ressources aquifères. Par contre les nappes du calcaire permo-carbonifère paraissent constituer une des plus abondantes des resources en eau. Ces calcaires très plissés par les orogénèses anciens sont affectés par des dislocations plus récentes et sont traversés par un réseau de fissures élargies ultérieurement. Ils sont très karstiques et affleurant sur des grandes surfaces, ils ont une énorme importance comme roche-magasin. Il existe sur le flanc N de l'Elmadağ, au S d'Ankara, une source utilisée depuis longtemps pour l'alimentation de la Capitale en eau potable. Le débit moyen de cette source, qui sort des calcaires permo-carbonifère à une altitude voisine de 1400 m, est d'environ 20 litres par seconde. Les vergers et les vignes sur les versants des vallées sont arrosés et irrigués par des sources sortant de ces calcaires.

Le Trias n'affleure que sur des étendues très réduites; il paraît n'avoir aucun intérêt au point de vue aquifère.

Le Crétacé supérieur et l'Eocène calcaire offrent des resources aquifères notables. La quantité d'eau donnée par ces calcaires dépend de leur degré de fissuration. Il est bien évident qu'une grande importance revient aux eaux profondes, mises en réserve dans ces immenses massifs calcaires karstiques.

Les niveaux conglomératiques du flysch du Crétacé et de l'Eocène présentent aussi quelques fois des terrains très perméables à la surface. Un forage dans ces niveaux au SW d'Ankara, profond de 45m, a fourni 20 litres d'eau par seconde, tandis que les niveaux argileux n'ont rien donnés jusqu'à 75 m.

* * *

Il est bien entendu que le présent rapport, consacré aux conditions climatiques, à la géologie et aux nappes existantes dans les alluvions (qui suivent évidemment les variations de niveau des cours d'eau) et dans les formations du Néogène de quelques ovas de l'Anatolie Centrale, ne vise pas à entrer dans le détail de chacun de ces domaines; mais à exposer l'ensemble des connaissances qui ont été acquises à leur sujet. Il résulte de cet exposé sommaire que la partie

n question de l'Anatolie Centrale n'est aride qu'artificiellement. L'eau existe, mais elle n'est as captée suffisamment pour être utilisée au cours des mois de sécheresse.

Il faudrait reconnaître qu'en Turquie, les recherches hydrogéologiques sur une grande chelle, en vue de préciser la capacité en eau souterraine de la partie centrale de l'Anatolie, 'ont commencé que depuis quelques années. Nous espérons que ces recherches conduites ous l'égide d'une organisation scientifique au Service d'Adduction d'Eau, aboutirons à la ise en valeur d'une vaste région actuellement considérée comme semi-désertique.

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GRAPHICAL SOLUTION OF GROUND WATER FLOW PROBLEMS

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ABSTRACT

Graphical solutions to linear and radial ground water flow problems are described. These metho are based on finite difference approximations which have been widely used in heat flow problems. Th case of the leaky aquiclude and vertical recharge to unconfined aquifers is discussed as well as consta head at a control and constant discharge or recharge. These solutions are useful only when the physica factors are known and an estimate of water level changes under certain conditions is desired. Th methods are not intended to replace more rigorous mathematical solutions.

INTRODUCTION

The fundamental ideas involved in graphical solutions to the various ground water flo problems suggested in this paper were originally derived for heat flow problems. The key t the solutions is a widely used finite difference approach which enables one to approximat water level changes relatively quickly and easily for many different boundary condition When the elements of the method are learned, it has the advantage of being usable even thoug other formulae, tables, curves, and reference books are not available. All that is require for the simpler linear flow problems, is paper, pencil, straightedge, and the imagination t simplify the actual field problem within reason.

The problems are based on linear and radial flow. In all cases, the aquifer is either con fined or, if it is unconfined, the changes in water level are less than 10% of the saturated thick ness. No attempt was made to derive a method for a thin unconfined aquifer. The case of a simple confined aquifer is presented in IA and IIA. The case of a confined aquifer with a leaky aquiclude is covered in cases IB and IIB. The case of a thick unconfined aquifer wit constant vertical recharge is shown in cases IC and IIC.

Conditions I and II are for the case of sudden head changes at a boundary which is the maintained while water levels in the aquifer adjust to the new conditions.

Condition III is for the case of a varying head at a control due to constant discharge o recharge at that control.

Some variations from these simpler conditions are also mentioned with suggested solu tions.

Accuracy of these methods depends not only on the method, but also on how well the physical parameters are matched. The methods themselves become more accurate as the dis tance and time increments are made smaller. The methods are most useful for first approxi mation type calculations where time and money are short and where precise answers are no required.

CONDITION IA LINEAR FLOW — CONSTANT HEAD

Assume linear flow in a homogeneous confined aquifer with equal transmissibility, T and storage coefficient, S. An unconfined aquifer of permeability P and thickness m, may also be considered by this method if the change in water level, h, is small compared with m

Divide the aquifer and the piezometric surface on the aquifer itself into a foot-wide slab n the direction of flow. The slab is divided into blocks Δx long separated by planes 0, 1, 2, tc. in the direction of flow. For this case assume a rise in piezometric level at plane 0 at time = 0 and maintained at a constant elevation. Using the notation of h to be elevation above oted that when $\Delta t = 0$, the superscript 0 is, for convenience, not written. The pre-initial vater surface, then h_1^1, h_2^1, h_3^1, h_4^1 means head at planes 1, 2, 3, etc. at times $\Delta t = 1$. Head t plane 1 and times $\Delta t = 1$, $\Delta t = 2$, $\Delta t = 3$, etc. is shown by h_1^1, h_1^2, h_1^3. It will be

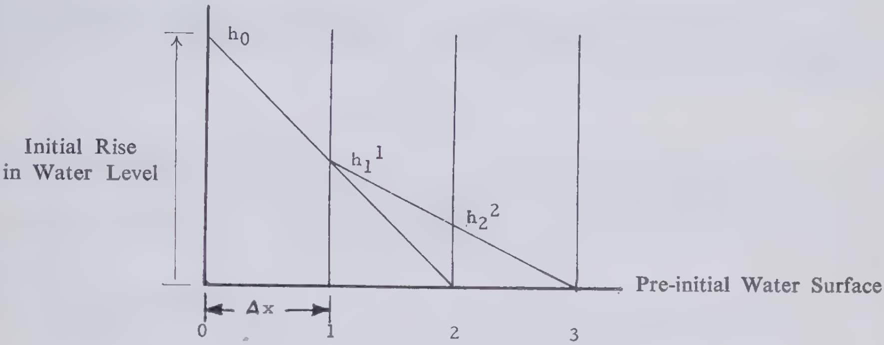


Fig. 1 — Construction of Graphical Solution

Inflow rate to plane one is $Q = PIA = TID$. Since $V = Q\Delta t$, then $V = TID\,\Delta t$ and nflow during time Δt is

$$V = T\,\Delta t\,(h_0 - h_1)/\Delta x \tag{1}$$

since D equals one.

Outflow from plane one during time Δt is

$$V = TID\,\Delta t = T\,\Delta t\,(h_1 - h_2)/\Delta x \tag{2}$$

Change of storage in a strip Δx long near plane one is

$$\Delta S = S\,\Delta x\,(h_1^1 - h_1) \tag{3}$$

Then, since inflow minus outflow equals change in storage,

$$T\,\Delta t\,(h_0 - h_1)/\Delta x) - (T\,\Delta t\,(h_1 - h_2)/\Delta x) = S\Delta x\,(h_1^1 - h_1) \tag{4}$$

Rearranging

$$(h_0 - h_1) - (h_1 - h_2) = (S\,\Delta x^2/T\Delta t)\,(h_1^1 - h_1) \tag{5}$$

if we let

$$S\,\Delta x^2/T\,\Delta t = 2 \tag{6}$$

then

$$h_0 - 2h_1 + h_2 = 2h_1^1 - 2h_1$$

or (7)

$$h_1^1 = (h_0 + h_2)/2$$

It will be noted that h_1^1 is obtained graphically simply by connecting h_0 and h_2 as shown in Figure 1.

Examples one and two illustrate a problem for confined and unconfined conditions respectively.

Condition IB — Linear Flow — Constant Head — Confined aquifer with leaky aquiclude

In the case of a confined aquifer with a leaky aquiclude, the vertical downward rate of movement of water per unit surface area is

$$Q_v = K\left(\frac{s}{b}\right) = sK/b \tag{8}$$

where K is the vertical permeability, b is the thickness of the aquiclude and s is the difference in head between the piezometric and semiperched water levels.

The total vertical percolation or leakage during time Δt over the width Δx is

$$Vv = (K/b)\, s\, \Delta t\, \Delta x \tag{9}$$

The leakage must be added to left side of equation (4) which becomes

$$\frac{K}{b} s\, \Delta t\, \Delta x + (T\, \Delta t\, (h_0 - h_1)/\Delta x) - (T\, \Delta t\, (h_1 - h_2)/\Delta x) = S\, \Delta x\, (h_1^1 - h_1)$$

or

$$\frac{K}{b}\,\frac{s\, \Delta x^2}{T} + (h_0 - h_1) - (h_1 - h_2) = \frac{S}{T}\,\frac{\Delta x^2}{\Delta t}(h_1^1 - h_1) \tag{10}$$

and if

$$\frac{S}{T}\,\frac{\Delta x^2}{\Delta t} = 2, \text{ then (10) becomes}$$

$$h = \frac{h_0 + h_2}{2} + \frac{K\, s\, \Delta x^2}{b\, 2\, T} \tag{11}$$

The head difference, s, is the only item in the last term of equation (11) which varies with head time and with the planes. Therefore let

$$Z = (K/b)\, \Delta x^2/2T \tag{12}$$

The procedure for obtaining h^1 is carried out and s is determined graphically. The value Zs is then added to the first estimate of h^1 to obtain a corrected h^1, as shown below in the non-numerical example in Figure 2.

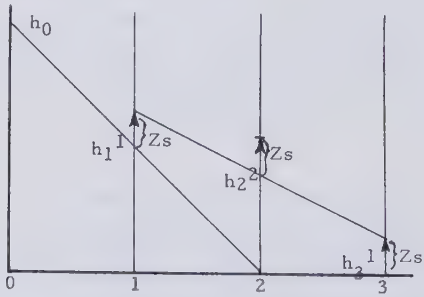


Fig. 2 — Graphical solution with a leaky aquiclude

Condition IC Linear Flow in Unconfined Aquifer with Constant Surface Recharge

Assume an unconfined homogeneous aquifer of constant permeability, P, with water level change, h, less than 10% of thickness, m, and with storage coefficient, S. Assume a constant downward percolation rate of W per unit area.

Subsurface inflow to a block Δx wide by one foot thick during time Δt is

$$V = Pm\, IA\, \Delta t = Pm\, \Delta t\, (h_0 - h_1)/\Delta x$$

Vertical surface inflow to plane 1 in a strip Δx wide on either side of plane 1 is $W\,\Delta x\,\Delta t$. Subsurface outflow from plane 1 is $Pm\,\Delta t\,(h_1 - h_2)/\Delta x$. Change of storage in a unit Δx wide on either side of plane 1 is

$$S\,\Delta x\,(h_1^1 - h_1)$$

Then

$$W\Delta x\,\Delta t + Pm\,\Delta t\,(h_0 - h_1)/\Delta x - Pm\,\Delta t\,(h_1 - h_2)/\Delta x = S\Delta x\,(h_1^1 - h_1) \tag{13}$$

Rearranging we get

$$(W\,\Delta x^2/Pm) + (h_0 - h_1) - (h_1 - h_2) = (S\,\Delta x^2/Pm\,\Delta t)(h_1^1 - h_1) \tag{14}$$

If

$$S\,\Delta x^2/2\,Pm\,\Delta t = 1$$

Then

$$(W\,\Delta x^2/Pm) + h_0 - 2h_1 + h_2 = 2h_1^1 - 2h_1$$

or

$$h_1^1 = (h_0 + h_2)/2 + W\,\Delta x^2/2\,Pm \tag{15}$$

When $S\,\Delta x^2/2\,Pm\,\Delta t = 1$ is given, values of Δx^2, Pm, S, and Δt are known or assigned, then
$W\,\Delta x^2/2Pm = WC/2$ where C is a constant
and finally

$$h_1 = (h_0 + h_2)/2 + WC \tag{16}$$

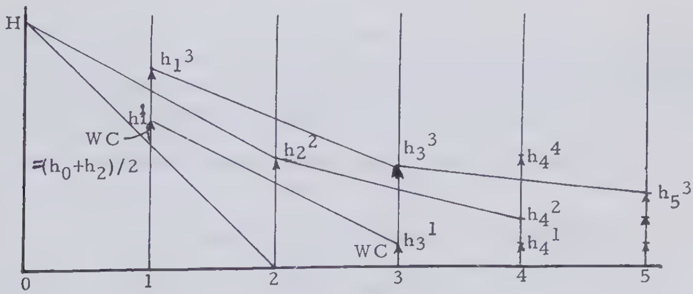


Fig. 3 — Graphical solution with constant vertical recharge

In the nonnumerical example above the water level is suddenly raised at plane O to H and by adding WC to each interpolated value a corrected h may be obtained. Example 4 illustrates this problem.

Condition IIA — Radial Flow — Constant Head

Assume an infinite homogeneous aquifer of equal transmissibility T and storage coefficient S. If water level changes, h, are small compared to the saturated thickness m, this method also applies to unconfined conditions. A pumping or recharge well penetrates the aquifer.

If we take a cylindrical surface at distance r (with other cylinders at r_0 and r_2 on either side), the inflow to the cylindrical surface is

$$Vi = 2\pi\, T\, \Delta t\, (h_0 - h_1)/(\ln r_1 - \ln r_0) \tag{17}$$

and outflow

$$V_0 = 2\pi\, T\, \Delta t\, (h_1 - h_2)/(\ln r_2 - \ln r_1) \tag{18}$$

Change in storage is $S\ 2\pi\, (\ln r_1 - \ln r_0)(h_1^1 - h_1)$ (19)

Now let

$$(\ln r_a - \ln r_b) = (\Delta \ln r) \tag{20}$$

By converting the naperian log to the base 10, we get

$$\Delta \ln r \text{ equals } 2.3\, \Delta \log r$$

and we can plot the distance on log paper and read off linear distances for ($\Delta \log r$).

The inflow-outflow equation becomes

$$[2\pi T \Delta t (h_0 - h_1)/2.3 \Delta \log r] - [2\pi T \Delta t (h_1 - h_2)/2.3 \Delta \log r] = 2\pi S\, (2.3) \Delta \log r\, (h_1^1 - h_1) \tag{21}$$

or

$$(h_0 - h_1) - (h_1 - h_2) = S\, 2.3\, \Delta \log r\, (h_1^1 - h_1)/T\, \Delta t / 2.3\, \Delta \log r)$$

or

$$h_0 - 2h_1 + h_2 = 5.3\, S\, (\Delta \log r)^2\, (h_1^1 - h_1)/T\, \Delta t \tag{22}$$

By letting

$$5.3\, S\, (\Delta \log r^2)/2\, T\, \Delta t = 1 \tag{23}$$

we get

$$h_0 - 2h_1 + h_2 = 2h_1^1 - 2h_1 \tag{24}$$

or

$$h_1^1 = h_0 + h_2/2$$

To get inflow or outflow use equation 17 or 18, therefore,

$$Q = 2\pi\, T\, \Delta t\, (h_0 - h_1)/2.30\, \Delta \log r \tag{25}$$

Examples 5 and 6 illustrate radial flow in confined and unconfined conditions respectively.

Condition IIB — Radial Flow—Constant Head—Confused aquefer with Leaky agewicluds.

For vertical percolation through a leaky aquiclude, Z of equation 12 becomes $Z' = 4.6\pi K\, (\Delta \log r)\, s\, (r_2^2 - r_1^2)\, /\, 2\, Tb$ (26)

where s is the difference between piezometric and semiperched water levels at the plane at the time of interest if

$$5.3\ S\ (\Delta \log r)^2 / 2\ T\Delta t = 1 \tag{27}$$

Example 7 illustrates this condition.

CONDITION IIC — Radial Flow in unconfined aquifer with Constant Surface Recharge.

For a constant areal recharge rate, equation 14 becomes

$$(W\,4.6\ (\Delta \log r)\ (r_2^2 - r_1^2) / Pm) + h_0 - 2h_1 + h_2 =$$

$$5.3\ \ (\Delta \log r)^2\ (h_1^1 - h_1) / Pm\,\Delta t \tag{28}$$

$$\text{or if } 5.3\ S\ (\Delta \log r)^2 / 2\ Pm\,\Delta t = 1$$

then

$$h_1^1 = (h_0 + h_2) / 2 + WC' / 2 \tag{29}$$

where

$$C' = 9.2\,\pi\,(\Delta \log r)\ (r_2^2 - r_1^2) / Pm$$

The value of $WC'/2$ is then added to the head obtained by $(h_0 + h_2)/2$ as in linear flow. Example 8 illustrates this condition.

CONDITION IIIA — CONSTANT RECHARGE OR DISCHARGE ALONG A LINE — LINEAR FLOW CONDITIONS

Recharge or extraction, Q, is from a line perpendicular to the direction of flow.
Initial conditions are known. Boundaries are known.
Assume a homogeneous confined aquifer or an unconfined aquifer of great thickness compared with the change in water level caused by the recharge.
Let Q be extraction or recharge rate per linear foot of line perpendicular to slab. Then V is the volume extracted in time Δt.

Theory

In planes other than the first one, the methods outlined previously are used. It is assumed that extraction or recharge at the plane is to one side only, therefore if the system is symmetrical (extends on both sides of the recharge or extraction line) the quantity Q must be divided. If, on the other hand, the recharge or discharge is at an impervious boundary, then total Q is used for the one side.

The important assumption here is that flow is stable in the first zone Δx at time $\Delta t = 1$ and that no other zones influence discharge. Therefore

$$Q = PIA = TIW = (h_1 - h_0)/\Delta x$$

or

$$(h_1 - h_0)/\Delta x = Q/T = \text{slope in first zone} \tag{30}$$

This initial slope is first constructed, then used for the standard construction. Th[e] process is repeated as shown diagrammatically below in Figure 4. Example 9 illustrates thi[s] problem.

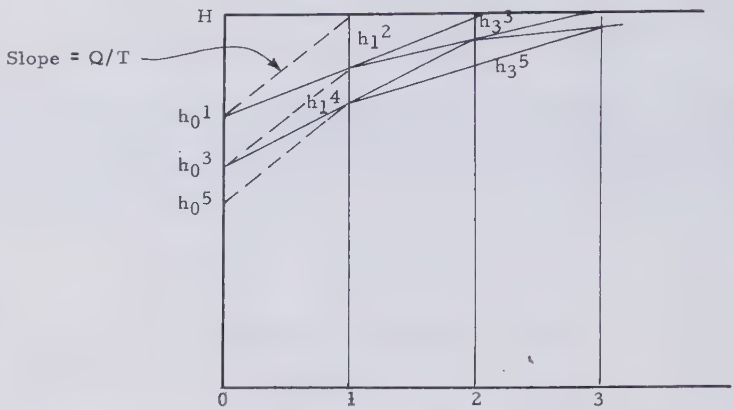


Fig. 4 — Graphical solution with constant discharge at one end of a linear flow system

Condition IIIB — Radial Flow — Constant Recharge or Discharge at a Point

Theory and practice should be fairly clear in the case of radial flow and a recharge or discharge well. Initial slope in the first zone is

$$Q = TIW = T(h_1 - h_0)\, 2\pi \,/\, 2.3\, \Delta \log r$$

or

$$(h_1 - h_0) \,/\, \Delta \log r = 2.3\, Q \,/\, 2\pi T = \text{Initial Slope} \tag{31}$$

Example 10 illustrates discharge at a well.

Variable Head at the Control

If, instead of a steady head at the control end of the problem, the head varies in some known manner, this can be easily handled graphically by using average heads at the respective Δt intervals, as shown in Example II.

Variable Line or Point Recharge or Discharge

If, instead of a constant recharge or discharge at the control end of a problem the quantity varies in some known manner, the averaged values of Q are used for the respective Δt intervals in equations (30) and (31). Example 12 illustrates this problem.

Variable Deep Percolation

If the deep percolation varies in a known way with time or with distance, the value of W should be altered accordingly in equations (16) and (29).

Variable Vertical Permeability and Aquiclude Thickness

In the case of a leaky aquifer the known changes with distance of the vertical permeability and thickness can be included in the computation of Z and Z' in equations (12) and (26).

Nonhomogeneous Aquifer

If the aquifer is nonhomogeneous and the values of S and T are known, a reference value of S/T is used and the real distances are adjusted on the graphical plot by

x (adjusted) $=$ x (actual) times $\sqrt{(S/T)}$ actual / $\sqrt{(S/T)}$reference

The standard methods are then used and the adjusted distances are converted back to the original distances to get a true water level picture.

Impervious Boundary

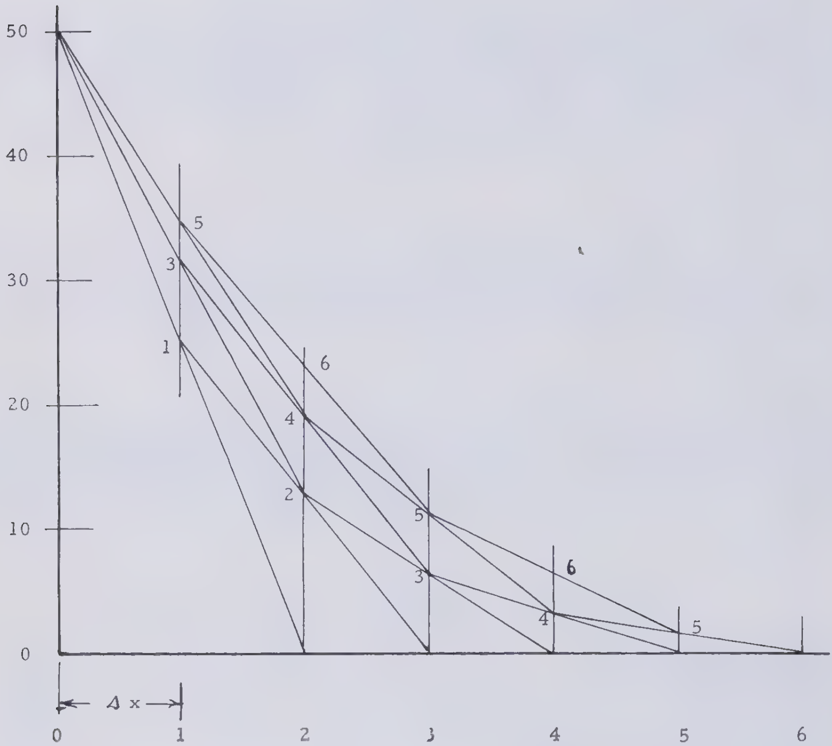
An impervious boundary is treated by the method of images. At the last Δx distance an imaginary Δx may be constructed for approximation fo the water level changes. A line is drawn horziontally for the first approximation as shown in Example 13.

Multiple Aquifers

If multiple aquifers exist, their hydrologic boundaries are defined and if reasonable formation factors can be assigned it may be possible to construct water level histories of the various aquifers using the methods outlined here. Transparent overlays may help in keeping events clear.

SYMBOLS

b	— Thickness of aquiclude	L
d	— Width of aquifer	L
h	— Water level above or below a reference elevation	L
I	— Hydraulic gradient	L/L
K	— Vertical permeability of aquiclude	$L^3/t/L^2$
m	— Thickness of aquifer	L
P	— Horizontal permeability of aquifer	$L^3/T/L^2$
Q	— Horizontal flow rate during a period of time, Δt, (equals $V/\Delta t$)	L^3/T
Qe	— Extraction rate per lineal foot or at a well	L^3/T
Qv	— Vertical flow during a period of time, Δt	L^3/T
r	— Distance from a well	L
S	— Storage coefficient	
s	— Difference in water level between semiperched water table and piezometric surface of underlying aquifer	L
T	— Transmissibility $= Pm$	$L^3/T/L$
t	— time	T
Δt	— A period of time, conveniently chosen	T
V	— Volume of flow during time Δt, (equals $Q\Delta t$)	L^3
W	— Rate of percolation per unit area	$L^3/T/L^2$
x	— Length of a part of a foot-wide slab	L
Z	— Vertical leakage	L^3/T



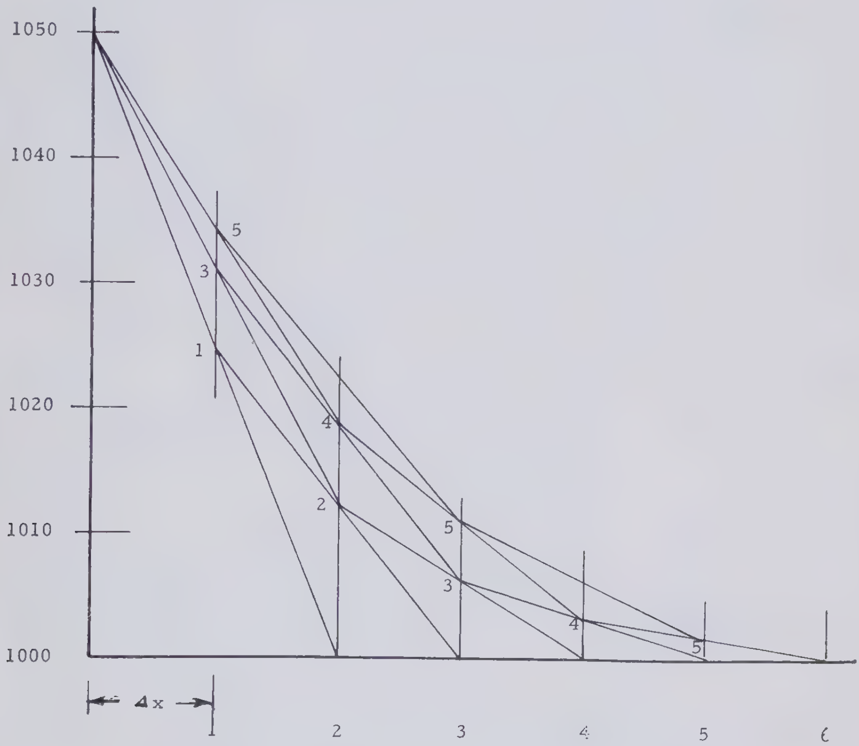
Example 1 — Linear Flow—Confined aquifer

$S = 2{\cdot}10^{-5}$ $T = 1.0$ cfs/ft

Water level suddenly raised 50 feet

If $S\,\Delta x^2/2T\Delta t = 1$
then $2{\cdot}10^{-5}\,\Delta x^2/2(1.0)\,\Delta t = 1$
or $\Delta x^2/\Delta t = 1(2)\,(1)/2{\cdot}10^{-5} = 10^5$

If we let $\Delta\ t = 5000$ sec
then $\Delta x^2 = 10^5{\cdot}5{\cdot}10^3 = 5{\cdot}10^8$
and $\Delta x = 2.24{\cdot}10^4$ Ft.
Rate of Flow at Plane 1 at $\Delta t = 5$ is
$Q_1^5 = T\,(h_0 - h_1)/\Delta x$
$= 1\,(50-34)/2.2{\cdot}10^4 = 6.9{\cdot}10^{-4}$ cfs.



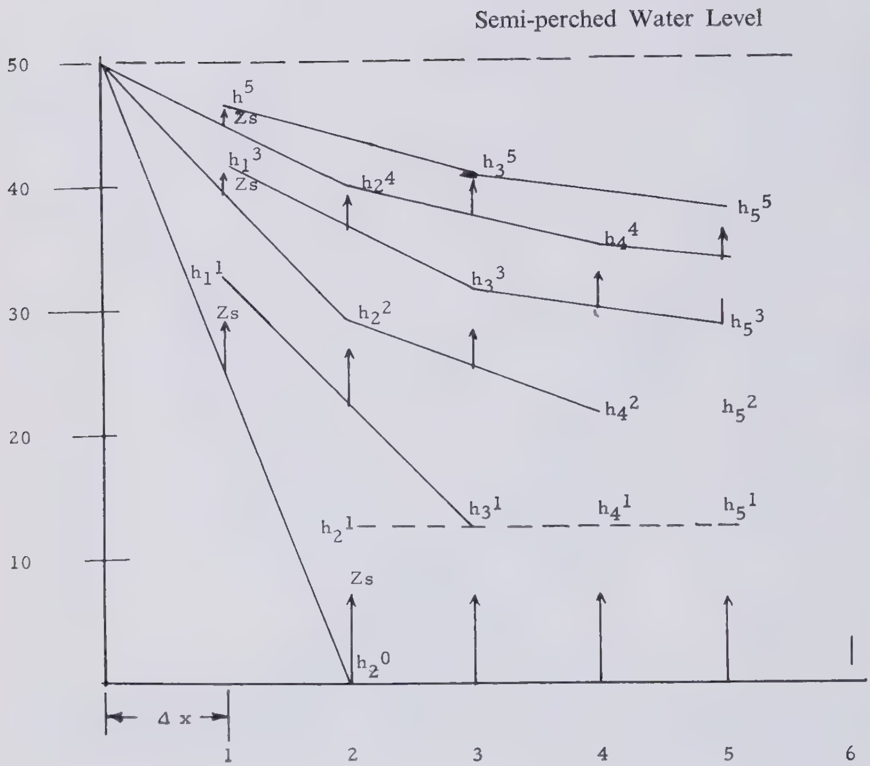
Example 2 — Linear Flow — Unconfined aquifer

$S = 0.10$ $P = 0.001$ cfs/ft^2
Aquifer originally 1000 Ft. thick and filled with
Water level suddenly raised to 1050 feet.

If $S\Delta x^2/2Pm\,\Delta t = 1$.
Then $0.1\ \Delta x^2/2\ (.001)\ 10^3\ \Delta t = 1$
and $\Delta x^2/\Delta t = 0.2\cdot10^{-2}$.

If we let $\Delta t = 5000$ sec.
then $\Delta x^2 = 10$ ft
and $\Delta x = 3.16$.
Rate of Flow at Plane 1 at $\Delta t = 5$ is

$$Q_1^5 = Pm\,(h_0 - h_1)/\Delta x$$
$$= 0.001\ (1000)\ 1050 - 1034/316$$
$$= 15/300 = 0.05 \text{ cfs.}$$

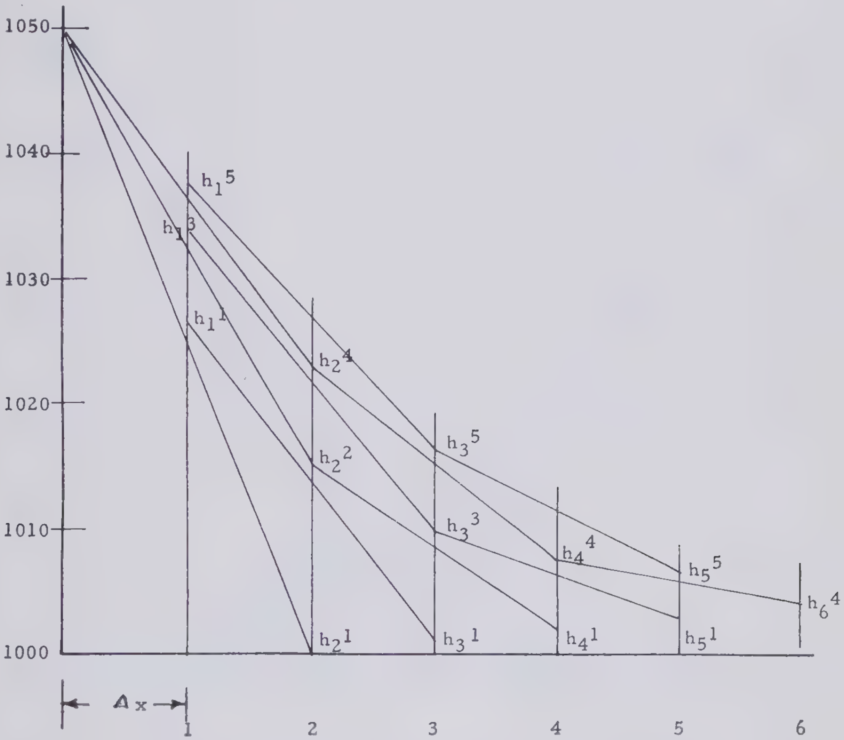


Example 3 — Linear Flow — Leaky aquiclude

$S = 2{\cdot}10^{-5}$ $\quad T = 1.0$ cfs/ft
$K/b = 10^{-9}$ cfs/ft²/ft
Piezometric level raised 50 feet.
Semi-perched water level at 50 feet.

If $S\Delta\, x^2/2T\Delta t = 1$
Then $\Delta x^2/\Delta t = 10^5$
If we let $\Delta t = 55\ 10^3$ sec

then $\Delta x^2 = 22.4{\cdot}10^4$ ft.
and $Z = K/b\,\Delta x^2/2T$
$= 10^{-9}{\cdot}5{\cdot}10^8/2{\cdot}1$
$= 0.25$ ft/ft
Correction Factor $= Zs$
Rate of Flow at Plane 1, $\Delta t = 5$ is
$Q_1^5 = T\,(h_0 - h_1)/\Delta x$
$= 1.0\,(50 - 46)/22.4{\cdot}10^4$
$= 1.78{\cdot}10^{-5}$ cfs

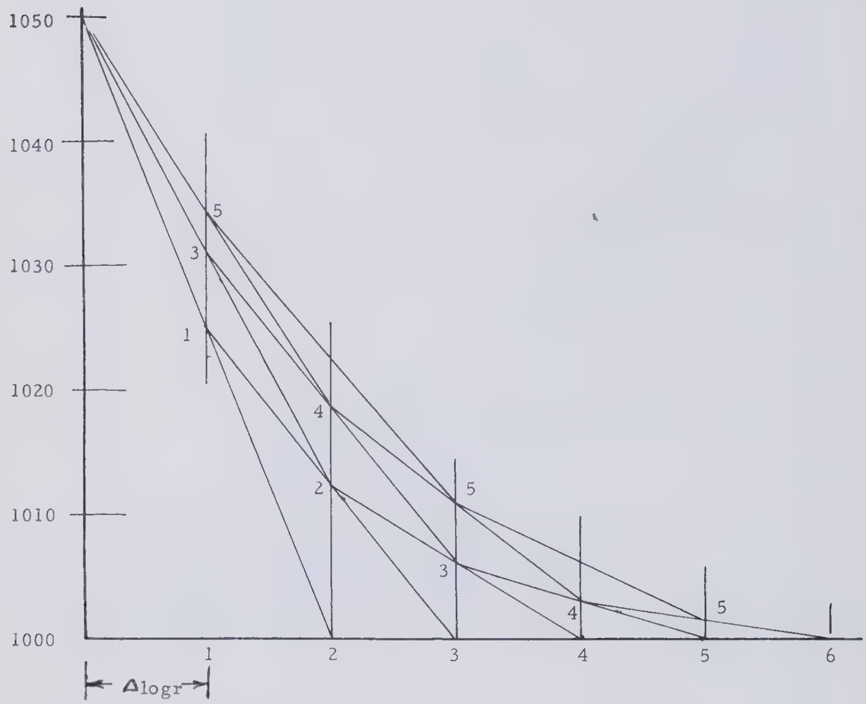


Example 4 — Linear Flow — Unconfined aquifer with constant surface recharge

$S = .10$ $\quad$ $P = .001$ cfs/ft²
$m = 1000$ ft. $\quad$ $W = 2{\cdot}10^{-5}$ cfs/ft²
Water Level suddenly raised 50 feet.
If $S\Delta x^2/2\ Pm\,\Delta t = 1$
then $\Delta x^2/\Delta t = 20$
If we let $\Delta t = 5000$ sec
then $\Delta x^2 = 10^5$

and $\Delta x = 316$ ft.
also $W\Delta x^2/2\ Pm = 2{\cdot}10^{-5}\ 10^5/2$
$= 1$ ft.
Rate of Flow at Plane 1 at $\Delta t = 5$ is

$$Q_1^5 = Pm\,(h_0 - h_1)/\Delta x$$
$$= 1\,(1050 - 1038)/316$$
$$= .037 \text{ cfs}$$

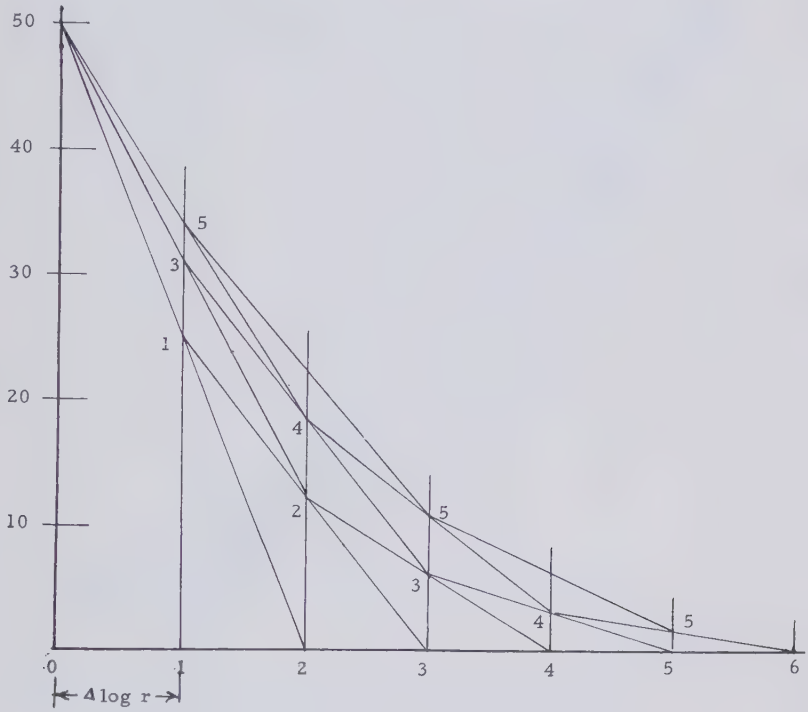


Example 5 — Radial Flow — Confined Aquifer

$S = 2 \cdot 10^{-5}$ $T = 1.0$ cfs/ft
Water level suddenly raised 50 feet.

If $5.35\,(\Delta \log r)^2/2T\,\Delta t = 1$
Then $5.3\,(2 \cdot 10^{-5})(\Delta \log r)^2/2\,(1.0)\,\Delta t = 1$
and $(\Delta \log r)^2/\Delta t = 1 \cdot 2 \cdot 1/5.3\,(2 \cdot 10^{-5})$
$= 1.88 \cdot 10^{-4}$

If we let $\Delta t = 5000$ sec.
then $(\Delta \log r)^2 = 9.4 \cdot 10^{-1}$
or $\Delta \log r = .97$
Rate of flow at Cylinder 1 At $\Delta t = 5$ is
$Q_1^5 = 2\pi\, T\, h_0 - h_1)/2.3\,(\Delta \log r)$
$= 2\pi\,(1.0)(50-34)/(2.3)(.97) = 100.8/2.23$
$= 40.71$ cfs



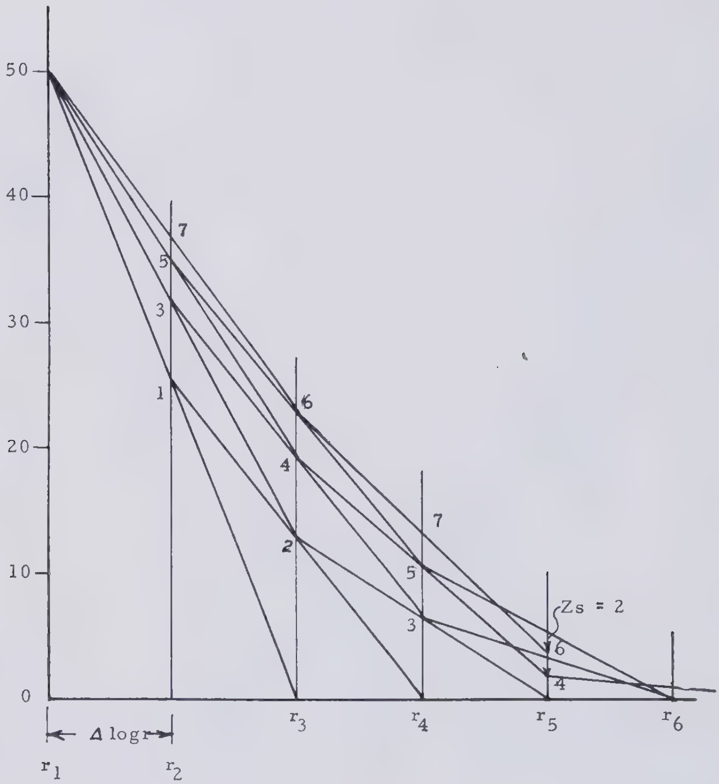
Example 6 — Radial Flow — Unconfined aquifer

$S = .10$ $P = .001$ cfs/ft^2 $m = 1000$
Aquifer originally 1000ft thick and filled with water
Water level suddenly raised to 1050 feet.

If $5.35\,(\Delta \log r)^2/2\,Pm\,\Delta t = 1$
then $5.3\,(.10)(\Delta \log r)^2/2(.001)\,10^3\,\Delta t = 1$
or $(\Delta \log r)^2/\Delta t = .002\,10^3/.53 = 3.76$

If we let $\Delta t = 500$ sec.
then $(\Delta \log r)^2 = 3.76 \cdot 5 \cdot 10^2$
or $(\Delta \log r) = 43.4$.
Rate of flow at cylinder 1 at $\Delta t = 5$ is

$$Q^1 = 2\pi\, Pm\, (h_0 - h_1)/2.3\, (\Delta \log r)$$
$$= 2\pi\, (.01)(1000)\, (1050-1034)/(2.3)\, 43.4$$
$$= 214.5 \text{ cfs.}$$



Example 7 — Radial Flow — Leaky aquiclude

Pièzometric Level suddenly raised 50 feet.
$S = 2 \times 10^{-5}$ $T = 1.0$ cfs/ft $K/b = 10^{-9}$
$(\Delta \log r)^2/\Delta t = 1.88 \times 10^{-4}$
Let $\Delta t = 5000$ sec.
then $\Delta \log r = .97$ (say 1.0)

radius ($\Delta \log r = 1.0$)	$r^2 - r$	Z
$r_1 = 1$	—	4×10^{-9}
$r_2 = 10$	99	4×10^{-7}
$r_3 = 100$	9900	4×10^{-5}
$r_4 = 1000$	990,000	4×10^{-3}
$r_5 = 10^4$	9.9×10^7	4×10^{-1}
$r_6 = 10^5$	9.9×10^9	4×10^1

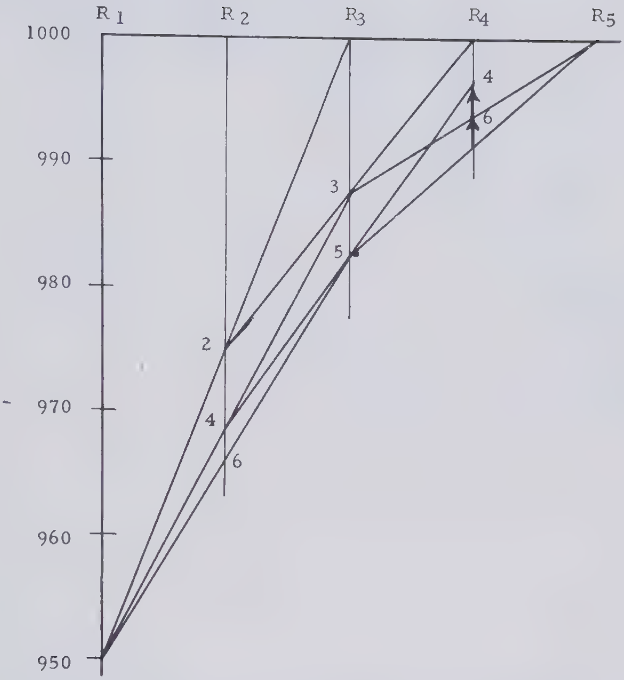
Semi-perched Level remains at 0 elevatio

$Z = 4.2\, K\, (\Delta \log r)\, (r^2 - r^2)/Tb$

At r_6 water levels would be sustained b downward leakage.

At r_4 at time $\Delta t = 7$, $Zs = 4 \times 10^{-3} \times (-1$ $= -.05$ and is negligible.

At r_5 at time $\Delta t = 6$, $Zs = 4 \times 10^{-1} \times (-$ $= -2$. This is first plane of noticeab effect within this time limit.

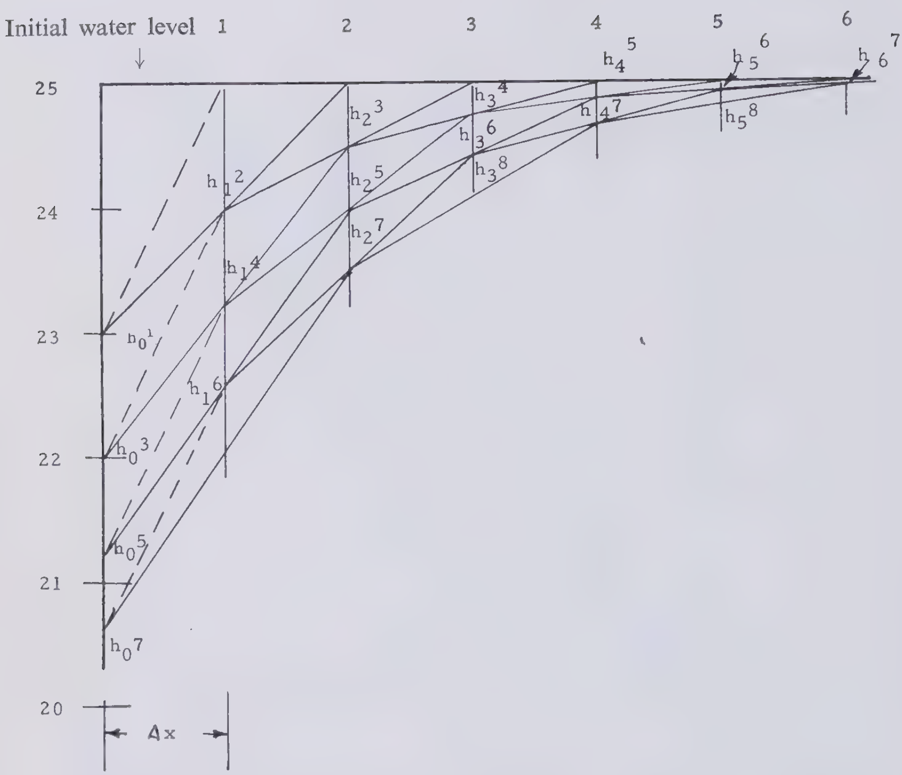


Example 8 — Radial Flow — Unconfined aquifer with constant surface recharge

$S = .10$ $P = .001$ cfs/ft² $m = 1000_7$
$W = 2 \times 10^{-7}$ cfs/ft²
Aquifer originally 1000 thick. Filled with water.
Water level suddenly lowered to 950 ft.

$(\Delta \log r)^2/\Delta t = 3.76$
if $\Delta \log r = 1$
then $\Delta t = .266$ sec.

and $C' = 9.2\,\pi(1)\,(r_2^2 - r_1^2)/(1)$
then $WC'/2 = 2.9\,(r_2^2 - r_1^2)\,2 \times 10^{-7}/2$
$= 2.9 \times 10^{-6}\,(r_2^2 - r_1^2)$
at r_2, $WC'/2 = 2.9 \times 10^{-4}$
at r_3, $WC'/2 = 2.9 \times 10^{-2}$
at r_4 $WC'/2 = 2.9$
at r_5 $WC'/2 = 290$ and aquifer would remain full due to surface recharge.



Example 9 — Linear Flow — Constant discharge to a ditch from a confined aquifer

$S = 2 \times 10^{-5}$ $T = 1.0$ cfs/ft

Discharge $= Q = 2.0$ cfs

$S = (\Delta x)^2/2T\Delta t = 1$

$\Delta x^2/\Delta t = 2(1)(1)/2 \times 10^{-5} = 10^5$

if $\Delta t = 5000$ Sec

$(\Delta x)^2 = 5 \times 10^8$

or $(\Delta X) = 2.16 \times 10^4$ ft

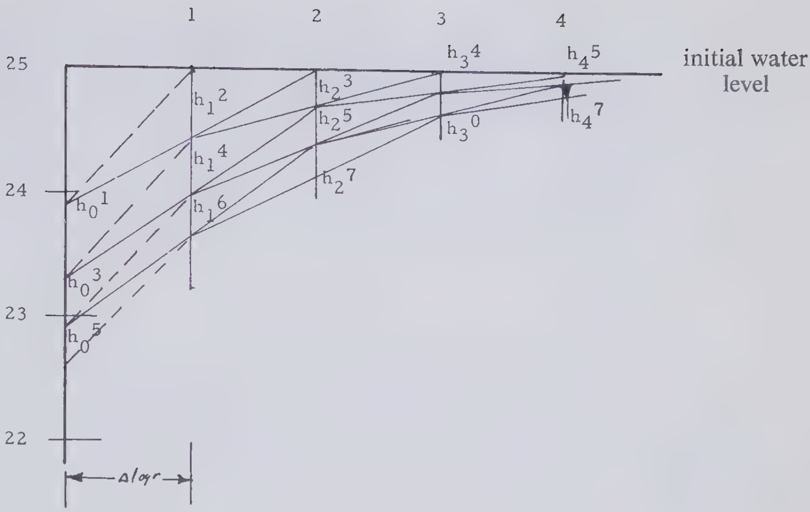
At Plane 0 to 1, $\Delta t = 1$

$h_0{}^1 = h_1 - Q/T = h_1 - 2/1 = 25 - 2 = 23$ fe

since $(h_1 - h_0)/\Delta x = Q/T =$ Slope in First Zo

and at $\Delta t > 1$

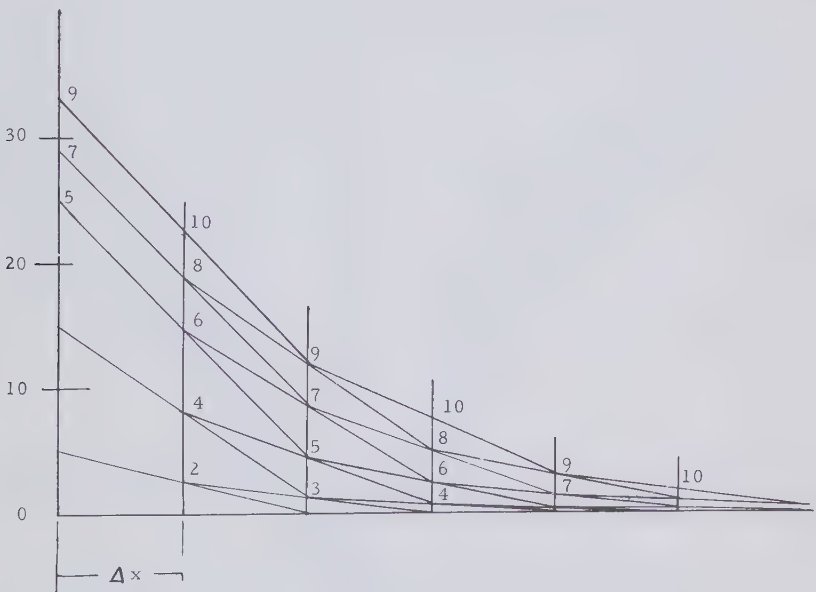
$h_0{}^{3,5} = h_1{}^{2,4} - Q/T = h_1{}^{2,4} - 2$



Example 10 — Radial Flow — Constant discharge to a well in a confined aquifer

$S = 2 \times 10^{-5}$
$T = 1.0$

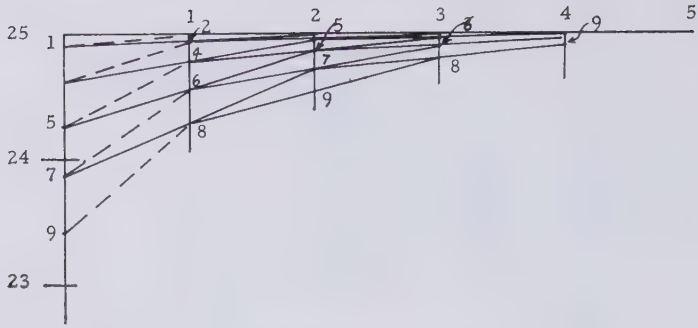
$Q = 3$
$Q = T 1 W = T[(h_1 - h_0)/(2.3 \Delta \log r)]\, 2\pi$
Initial Slope $= (h_1 - h_0)/\Delta \log r = 2.3 Q/2\pi T$
$= 6.9/6.28 = 1.1$



Example 11 — Linear Flow — Variable head at a boundary

Head at Plane 0 raises 5 ft per Δt starting at 0
at $\Delta t = 1$, $h^2 = 5$ ft
$\Delta t = 3$, $h_0^3 = 15$ ft.

After $\Delta t = 5$ recharge is reduced to a rise of 2 ft per Δt.



Example 12 — Linear Flow — Variable discharge from a confined aquifer to a ditch

$S = 2 \times 10^{-5}$ $T = 1.$ is cfs/ft

at each 5000 seconds Q increases by 0.1 cfs.

$\Delta x^2/\Delta t = 10^5$

if $\Delta t = 5000$ sec.

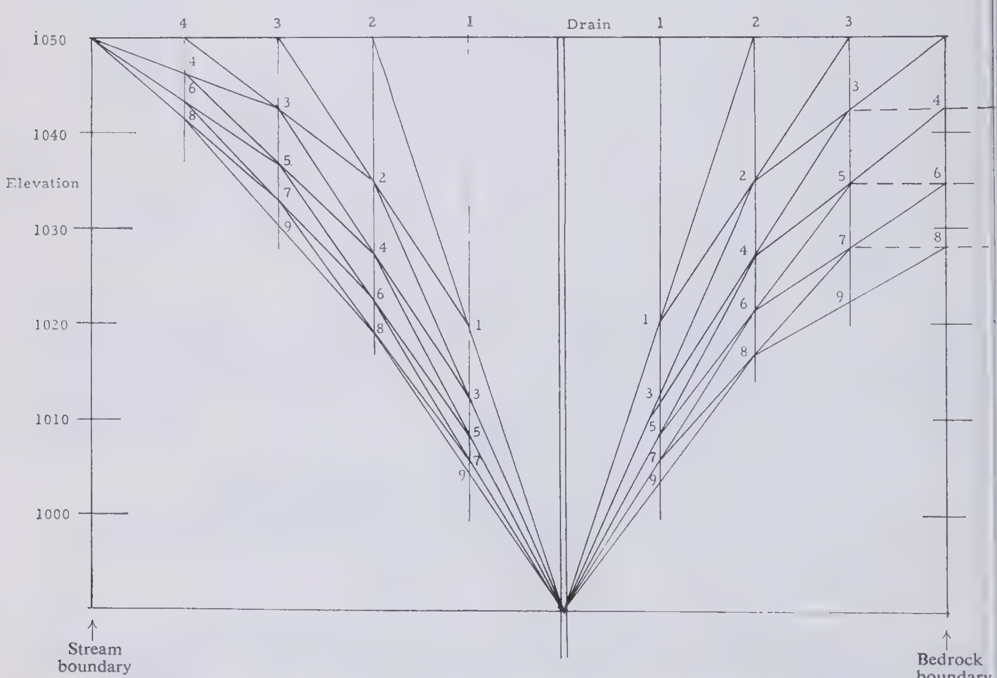
$\Delta x^2 = 5 \times 10^8, \Delta x = 2.16 \times 10^4$

slope in first zone at $\Delta t = 1$

$Q/T = .1/1 = .1$

at $\Delta t = 2$, $Q = .2$ and $Q/T = .2$

at $\Delta t = 3$, $Q = .3$, and $Q/T = .3$, etc.



Example 13 — Impervious and stream boundaries — Unconfined thick aquifer

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SOME METHODICAL ASPECTS OF GROUND WATER FORECASTING

(Presented at the Symposium of Athens)

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Warsaw Polytechnical Institute

The measure of fluctuations in ground water resources is water level as recorded in measurement wells. If we are interested in the future values of water resources we must proceed to forecasting the levels in the wells situated in the area under consideration. Owing to considerable inertia of hydrogeological processes not only short-term, but also long-term forecasts may be worked out, e.g. for several months in advance.

Any hydrological forecast should include the best possible description of the future course of the phenomenon under investigation. Its merit depends, above all, on the extent to which we have grasped the whole of natural processes resulting ultimately in the event which is being investigated. For, in working out a forecast, we make use of natural relationships existing between the predicted phenomenon and the combination of factors involved in producing it. Ground water forecast relations may be established by theoretically analyzing natural processes which determine the fluctuations of water resources. But, with the present - day scientific knowledge, it is extremely difficult to obtain by this means results which would be useful in practice. For this reason, in predicting we use more frequently empirical relationships between the predictands and a number of potential predictors which, we are justified to suppose, affect the predictands under consideration. It is customary to establish such empirical relationships by means of statistical methods.

For practical reasons simplified relation usually serve as basis for prediction, a number of factors of secondary importance being disregarded, as well as those elements which are either not observed at all or cannot be established at the time of forecasting. The effects of disregarded factors result in discrepancies between the predicted and actual values of the phenomena under consideration. These discrepancies are of random character, since they depend on a combination of the elements, disregarded in calculation, each of which may, at random, have, various values. We are not going to analyze the concept of randomness in the present paper, the intuitive interpretation of same being considered as sufficient. The discrepancies mentioned are directly due to the fact that the predictands determined on the basis of simplified causal relations are of random character, and are dependent on a number of unknown elements producing various effects. Let us now consider this problem in greater detail.

Suppose that ground water level y may have various values as a result of the effects of a number of factors x_i

$$y = y(x_1, x_2, \dots x_r) \tag{1}$$

If causal relationship (1) has not been found out, or if values of x_i are unknown, we say event y is of random character. Random phenomena are usually investigated on the basis of the probability theory as they conform only with statistical regularities. For an arbitrary random value we can always establish the probability

$$p = P(y \geqslant y_p) \tag{2}$$

which in hydrological applications is usually represented in the form of

$$y_p = H(g_1, \dots g_m, p) \tag{3}$$

Function H depends on the assumed type of probability distribution, and the values of g are the statistical parameters.

Let us now assume that we know a number of factors which influence event y, namely $x_1 \dots x_k$, where $k < r$. This is a situation which arises in predicting hydrological and meteorological phenomena. The event y predicted on the basis of the values $x_1 \dots x_k$ keeps its random character because a number of factors x_i continue unknown, the degree of randomness, however, is changed and so the probability distribution of y will be different. In this instance we shall speak of conditional probability, and shall represent it in the form of

$$p = P(y \geqslant y_p \,/\, x_1 \dots x_k) \tag{4}$$

or

$$y_p = H_c(g_{1c} \dots g_{mc}, p) \tag{5}$$

Each of the conditional parameters g_{ic} depends on the given predictors $x_1 \dots x_k$. It should be pointed out that one of this parameters is usually a conditional mean value $\bar{y}_c$.

The widespread notion that in forecasting we predict an actual course of the event in question is erroneous. In reality we define, as usually practised hitherto, only its conditional mean value (e.g. by the method of least squares), corresponding to a number of given predictors. The more elements of x_i are taken into account, the lesser the deviations of actual values from the calculated conditional means.

It follows however, from the above consideration, that on the basis of the knowledge of predictors $x_1 \dots x_k$, not only the value of $\bar{y}_c$, but all the other conditional parameters can be defined, as well as conditional distribution obtained from the relationship (5). The possibility of forecasting the value of y_E is equivalent to the prediction of the phenomenon in question with a given confidence level. The practical value of such conception of forecasting is obvious. The thesis about the random or probabilistic character of forecasting has appeard a number of times in hydrological literature. In these works, however, no sufficiently general solution is found. The subsequent part of this paper deals with the establishment of general methods of working out conditional distribution for predicted values. We leave it to the reader to acquaint himself with the general theory of this problem ([2]), and here we present only informations necessary for practical forecasting.

The general form of the relationships (4) or (5) is complicated and as a rule of no use for practical calculations. These formulas may have for us a real value only in the particular case when the probability of a joint occurrence of predictand u_0 and predictors $u_1 \dots u_k$ is defined by means of multidimensional normal distribution with a frequency function expressed in the formula

$$f(u_0, \dots u_k) = \frac{1}{(2\pi)^{k+1/2}\sigma_0 \dots \sigma_k \sqrt{P}} \exp\left[-\frac{1}{2P}\sum_{0}^{k} P_{ij}\,\frac{u_i - \bar{u}_i}{\sigma_i}\cdot\frac{u_j - \bar{u}_j}{\sigma_j}\right] \tag{6}$$

The value of P is a determinant of correlation matrix

$$P = \begin{vmatrix} 1 & r_{01} & r_{02} & \dots & r_{0k} \\ r_{10} & 1 & r_{12} & \dots & r_{1k} \\ r_{20} & r_{21} & 1 & \dots & r_{2k} \\ . & . & . & \dots & . \\ . & . & . & \dots & . \\ r_{k0} & r_{k1} & r_{k2} & \dots & 1 \end{vmatrix} \tag{7}$$

whereas P_{ij} are cofactors in the same matrix (i.e. minors multiplied by $(-1)^{i+j}$). The values of $\bar{u}_i$ and σ_i denote the arithmetical mean and the mean deviation of random variable u_i, respectively.

In ground water forecasting, however, joint probability distribution of the phenomen differs usually from normal. This difficulty can be avoided by the transformation of the system of variables (y, x_i) into a system (u_0, u_i) which is liable to normal distribution. It is possibly t show that such a transformation always exist, but in practice it is very difficult to find it. We shall make use of an approximate solution, and transform aech of the variables in the system (y, x_i) into a corresponding variable with a one-dimensional normal distribution

$$\begin{aligned} u_0 &= \varphi_0(y) \\ u_1 &= \varphi_1(x_1) \\ \cdot\cdot \quad & \quad \cdot\cdot\cdot\cdot \\ \cdot\cdot \quad & \quad \cdot\cdot\cdot\cdot \\ u_k &= \varphi_k(x_k) \end{aligned} \tag{8}$$

In accordance with terminology of the theory of probability, the relationships (8) are a transformation of marginal distribution of multidimensional variable. The accuracy obtained in transforming marginal distribution is sufficient for practical forecasting.

The shape of functions (8) should be established empirically in such a way as to fulfil normality requirements for the distribution of each of the variables transformed. The test can be effected graphically: numerical values of any of the variables u_i plotted on an normal probability scale should lie along a straight line. It is noteworthy that satisfactory results are usually obtained from logarithmic transformation

$$u_i = \log(x_i - c)$$

the value of c being found by experiment. The relationships of type (8) can also be determined in a graphical way. To do so, numerical values of variable x (or y) are shown on the normal probability scale, and at the same time an arbitrary straight line is drawn representing the distribution of variable u_i. Then, by plotting points x and u, which correspond to the same probabilities p on the perpendicular coordinates, we can draw up a diagram of function φ.

In practice we usually have at our disposal a number of numerical values of each of the variables y and x_i, obtained by making necessary observations during some years. Thus when all the transforming functions have been established, we can determine numerical values of all the variables u_i. On the basis of N-elements statistical series we shall then compute parameters $\bar{u}_i$, σ_i and correlation coefficients r_{ii} between the variables u_i and u_i $(i, j = 0, 1 \ldots k)$. In this way we arrive at all the necessary initial data.

Now let us go back to the problem of forecasting. In the particular case of normal variables the conditional distribution for the transformed predictand u_0 can be presented in one of the forms

$$p = P(u_0 \geqslant u_{0p}/u_1 \ldots u9) = \frac{1}{\sqrt{2\pi}\sigma_c} \int_{u_{0p}}^{\infty} e^{-\frac{(u_0 - \bar{u}_{0c})^2}{2\sigma_c^2}} du_0 \tag{9}$$

or after transformation

$$u_{0p} = \bar{u}_{0c} + t_p . \sigma_c \tag{10}$$

where the conditional mean

$$\bar{u}_{0c} = \bar{u}_0 - \frac{\sigma_0}{P_{00}} \sum_1^k P_{0i} \frac{(u_i - \bar{u}_i)}{\sigma_i} \tag{11}$$

and the conditional mean deviation

$$\sigma_c = \sigma_0 \sqrt{\frac{P}{P_{00}}} \tag{12}$$

The values t_p in the relationship (10) depend only on the assumed probability p, for instance

$$\begin{aligned} p &= 1\% \quad , \quad t_p = 2{,}326 \\ p &= 10\% \quad , \quad t_p = 1{,}282 \\ p &= 20\% \quad , \quad t_p = 0{,}842 \\ p &= 50\% \quad , \quad t_p = 0{,}000 \\ p &= 80\% \quad , \quad t_p = -0{,}842 \\ p &= 90\% \quad ; \quad t_p = -1{,}282 \end{aligned}$$

It follows from the above that in the case when variables in question are liable to normal multidimensional distribution, no difficulty is encountered in determining conditional distribution by means of formula (10), as it is only necessary to know the basic parameters (mean value, mean deviation, coefficient of correlation) for all the variables under investigation. Using the inverse function

$$y = \psi_0 (u_0) \tag{13}$$

we shall evaluate the forecasted values of y_p.

The methods of forecasting by means of conditional probability distribution, presented above, are sufficiently general to be applied when k is an arbitrary number of predictors. An increase in the number of predictors makes calculations more difficult, but purely from the technical point of view. When k is very large, it may be advisable to use electronic computers.

More complicated is the question of combined forecasts of a number of predictands $y_1 \ldots y_s$, discussed in detail in the papers ([5], [6]). In that case forecasts are based on multidimensional normal conditional probability distributions. In addition to conditional mean and mean deviation (computed for each predictand), conditional correlation coefficients between predictands are also obtained. In forecasting of ground water levels for number of wells (or for several points of time), these conditional correlation coefficients are not of practical use, and instead of multidimensional forecasting a number of simple one—dimension forecasts, for each well separately, may be worked out. In the Warsaw Polytechnic Institute was made an universal programme for the electronic computer UMC-1, where the forecasts are based on the multidimensional conditional distributions.

The interpretation of values y_p obtained from the formulas (10) and (13) is very simple. Let us suppose that for a given measurement well we forecast the water level at the May 1th and obtaine following values

$$\begin{aligned} y\,10\% &= 76{,}34 \text{ m} \\ y\,50\% &= 76{,}16 \text{ m} \\ y\,90\% &= 76{,}06 \text{ m} \end{aligned}$$

It means that the most probable value of the water level at the beginning of May will be 76,16 m. With a probability $p = 10\%$ this level will be higher than 76,34 m and less than 76, 06 m. So with the confidence level 80% we shall find y within the limits 76,06 m and 76,34 m.

If we want to apply the computation methods discussed above to practical problems of ground water level forecasting, it is first of all necessary to consider the choice of predictands and predictors.

Generally, the predictand is the water level value in a given measurement well at a definite moment of time. As regards the choise of potential predictors, they should certainly be differentiated depending on local conditions. As a rule, two general cases are possibly:

a) when autocorrelation relationships serve as basis of forecasting, i.e. when future ground water levels are predicted solely by inference from the levels occuring in the past, on the basis of established correlation relation—ships between water levels at various moments of time. In this case the past values of water level in the well under consideration are elements of the set of potential predictors x_i.

b) when various hydrometeorological elements, shaping ground water balance, are used in calculation, since ultimately ground water level depends on that balance. In this case the set of predictors include in the first place rainfalls, snow cover, winter thermal conditions and so on.

It should be pointed out that ground water levels show usually high autocorrelation coefficients, and that in forecasting it is sufficient, in many instance, to use relationships of this kind.

A more detailed discussion of the choice of predictors is not intended in this paper, the calculation technique which makes it possible to work out forecasts in the form of conditional probability distributions of our predictands.

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SHORT RANGE SNOWMELT FORECASTS (1)

VAIL P. SCHERMERHORN (2)

ABSTRACT

A simple temperature index for day-to-day forecasting of snowmelt runoff is described. The index is based on the unit hydrograph principle and is constructed by weighting antecedent temperatures in proportion to the ordinates of the basin's snowmelt unit graph.

To complement the temperature index, a contributing area index is developed using the variation in seasonal flow between two adjacent basins with different area-elevation characteristics.

INTRODUCTION

The U.S. Weather Bureau River Forecast Center prepares daily short range forecasts of snowmelt runoff for each of the principal Columbia River tributaries throughout the snowmelt season. These tributary forecasts are combined to yield forecasts of daily inflow to the principal reservoirs and, ultimately, daily stage forecasts for the Portland and Vancouver harbors and other downstream areas. Although several different methods are used, most tributary forecasts are based on a simple temperature index which varies proportionally with streamflow. The construction and use of the temperature index is described, together with a complementary contributing area index which may also be found useful in other methods of short range forecasting.

The methods will be illustrated on a portion of the Kootenay Basin in British Columbia. We have termed the 4100 square mile West Kootenay area between Porthill, Idaho and Corra Linn, B.C., shown in Figure 1, as Kootenay Lake Local Inflow. Temperature stations used are Crescent Valley and Old Glory Mountain. The 450 square mile Salmo basin, adjacent to the Kootenay on the southwest, is used as an index in the second part of this paper.

THE TEMPERATURE INDEX

The unit hydrograph is a common tool for the distribution of rainfall runoff, and it has also been used for many years to forecast snowmelt runoff. Because of the long time base characteristic of the snowmelt unit graph, its application by manual methods is rather tedious. By making several simplifying assumptions, the principle can be applied to temperatures to yield a quickly computed daily index which is proportional to daily streamflow.

In the large basins with which we deal, snowmelt unit graphs must usually be derived by trial and error, for it is impossible to isolate the runoff from a given day's melt. Likewise, the effectiveness of previous days' temperatures, or the temperature weights we seek for our index must also be determined by trial and error.

Daily mean temperatures were plotted on the hydrographs for the ten years studied. The 1951 season is used for illustration in Figure 2. A comparison of temperatures and discharge shows several conservative characteristics of the basin. First, it discloses the proper base temperature, below which there is negligible melt and above which we compute degree days or temperature excess. The base temperature is dependent on the elevation of the temperature stations used, and it would preferably increase during the season with the increasing

(1) Presented at the April 1961 meeting of the Western Snow Conference, Spokane, Washington, and contained in the Proceedings of that organization.
(2) U.S. Weather Bureau River Forecast Center, Portland, Oreg.

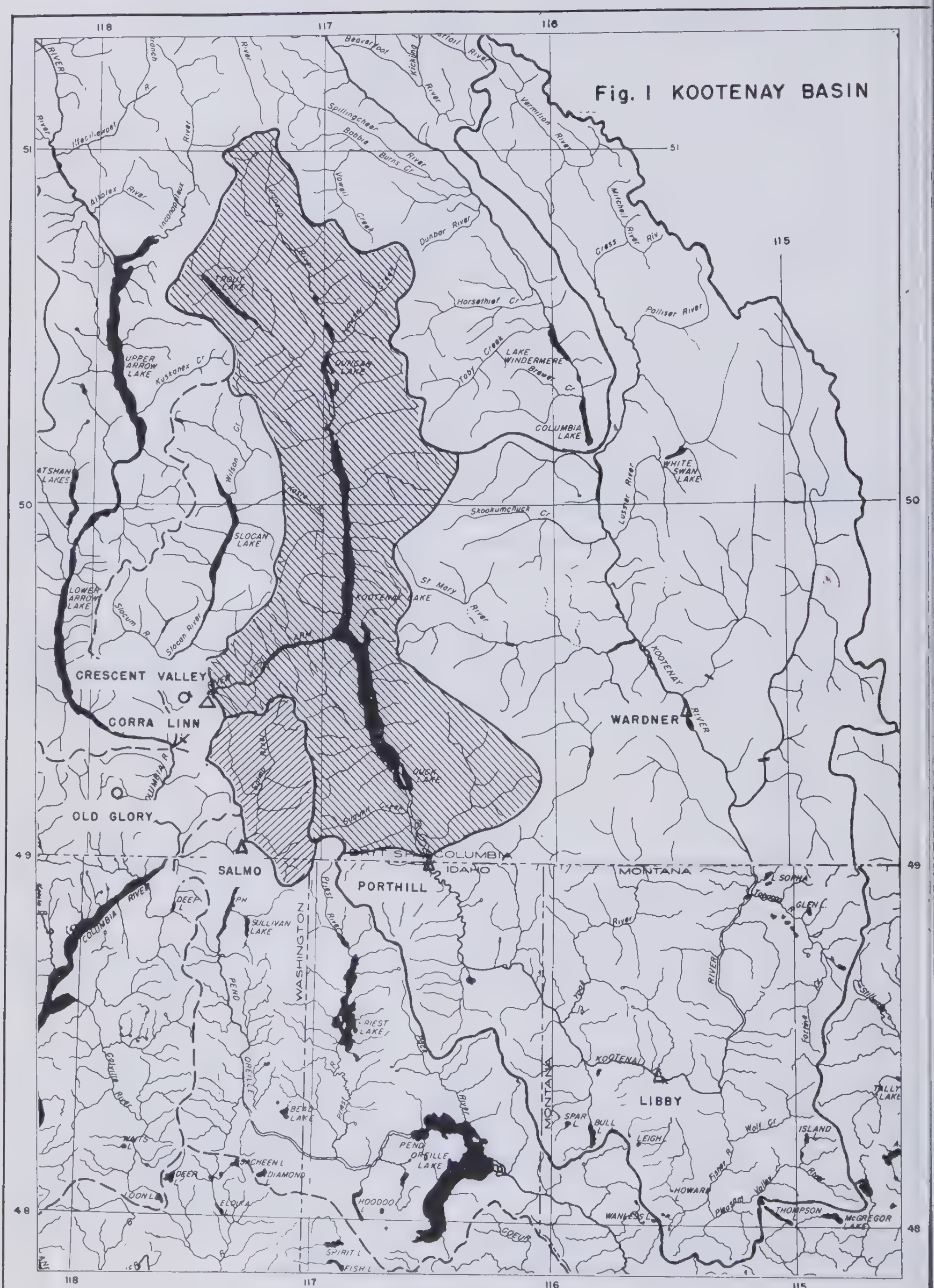
Fig. I KOOTENAY BASIN
CRESCENT VALLEY
CORRA LINN
OLD GLORY
SALMO
PORTHILL
WARDNER
LIBBY
UPPER ARROW LAKE
LOWER ARROW LAKE
TROUT LAKE
DUNCAN LAKE
SLOCAN LAKE
KOOTENAY LAKE
DUCK LAKE
LAKE WINDERMERE
COLUMBIA LAKE
WHITE SWAN LAKE
SULLIVAN LAKE
PRIEST LAKE
PEND OREILLE LAKE
BRITISH COLUMBIA
IDAHO
MONTANA
WASHINGTON
Skookumchuck Cr
St Mary River
Dunbar River
Horsethief Cr
Toby Creek
Palliser River
Lussier River
Slocan River
Kuskonex Cr
Wilson Cr
Spillimacheen River
Vermilion River
Beaverfoot
Kicking Horse River
Cross River
Kootenay River
Columbia River
Priest River
Pend Oreille
Colville River
Fisher R
Wolf Cr
Tobacco R
Yaak R
THOMPSON
McGREGOR LAKE
SPIRIT L
FISH L
118
117
116
115
51
50
49
48

average elevation of the melting zone. For simplicity it has been held constant at 30 degrees in this study.

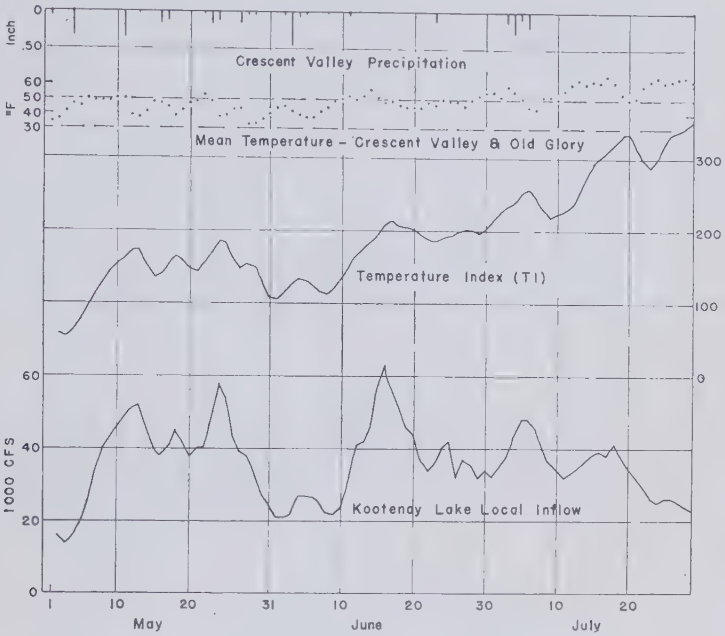

Fig. 2

A consistent time difference between peak temperature and peak discharge will be found, and this indicates which antecedent day's temperature should receive maximum weight in the index.

When temperatures drop sharply so that no temperature excess occurs for several days, the hydrograph will exhibit the recession characteristics of the basin. Most streams will approximate a logarithmic recession over a reasonably wide range of flow, that is, one day's flow is a constant percentage of the previous day's flow. From this characteristic comes the simplification which makes the temperature index useful—the effect of all temperatures more than two or three days ago can be combined in a single number which declines each day by this same percentage, or recession constant.

After the foregoing characteristics have been determined, trials are made of various weights for the first several antecedent days' temperature excess to find the index which varies with discharge in the most nearly linear manner. For simplicity, weights should be those which can be applied mentally such as 1/2, 1, 2 or 3.

The computation method can be illustrated by following the example in Figure 3. The temperature index (*TI*) of 131 on the 8th is the sum of one-half T_{E-1} (10) plus 2 T_{E-2} (40) plus 2 T_{E-3} (30) plus T_R (51), the temperature recession. This T_R value, in turn, is the sum of T_{E-4} plus .85 T_{E-5} plus .72 (.85^2) T_{E-6}, etc. The .85 *YDA* (yesterday's) T_R values are quickly copied from an .85 factor table, and the four numbers composing the *TI* are outlined for easy addition by a template which covers all but the values shown in the boxes.

To illustrate that the *TI* has the characteristics we wish, let us examine the *TI* values computed from a hypothetical one day temperature excess, as shown in the lower portion of

Figure 3. Adding in template order yields a series of *TI* values which clearly has the "uni graph" shape we would expect to see in the discharge hydrograph.

Fig. 3 — Temperature Index Computation

MAY, 1951

	Date:	1	2	3	4	5	6	7	8	9	10	11
Crescent Valley	Max	50	59	70	72	73	74	77	70	74	79	79
	Min	39	36	30	38	41	44	39	49	45	38	46
Old Glory	Max	24	29	40	40	40	43	45	42	45	49	44
	Min	21	19	25	33	26	38	35	34	33	35	31
	Sum	134	143	165	183	180	199	196	195	197	201	200
Mean	T	34	36	41	46	45	50	49	49	49	50	50
Temp. Excess	T_E	4	6	11	16	15	20	19	19	19	20	20
.85 YDA	T_R	30	29	30	35	43	49	59	66	72	77	82
Temp. Recession	T_R	34	35	41	51	58	69	78	85	91	97	102
	2 T_E	8	12	22	32	30	40	38	38	38	40	40
	.5 T_E	2	3	6	8	8	10	10	10	10	10	10
Temp. Index	TI		57	55	61	76	97	113	131	146	155	164

Hypothetical one day melt

		1	2	3	4	5	6	7	8	9	10	11
	T_E	0	0	20	0	0	0	0	0	0	0	0
.85 YDA	T_R			0	17	14	12	10	9			
	T_R	0	0	20	17	14	12	10	9			
	2 T_E	0	0	40	0	0	0	0	0			
	.5 T_E	0	0	10	0	0	0	0	0			
	TI			0	10	40	40	20	17	14	12	10

Referring back to Figure 2, we see that there is good general agreement between the shap of the *TI* curve and discharge. A closer check on the adequacy of the *TI* as a forecasting too comes from plotting daily discharge against concurrent values of *TI*. Figure 4a shows the relatio for the three principal rises of 1951 while Figure 4b shows several major rises of other years Generally only the rising limb of the curve has been shown to avoid cluttering the graph, an because the recession is frequently distorted by rainfall runoff. A lengthy discussion of th latter is beyond the scope of this paper, but we should obviously avoid periods of significan rainfall in deriving the *TI*. In forecasting, rainfall runoff must be added to the compute snowmelt discharge. Small amounts of rain can be treated as an equivalent temperature exces and included in the *TI*. Intense rains usually cause more rapid runoff and are handled wit a properly timed unit hydrograph.

Although the *TI* is not very sensitive to small fluctuations in temperature, it should b noted that the "wobbles" in the $TI-Q$ curve are not all due to inadequacy of the *TI*. Dail discharges for this area are computed by subtracting the flow at Porthill from the total inflow t Kootenay Lake. The effects of wind on the lake stage add to the variations inherent in the resi dual from a subtractive process.

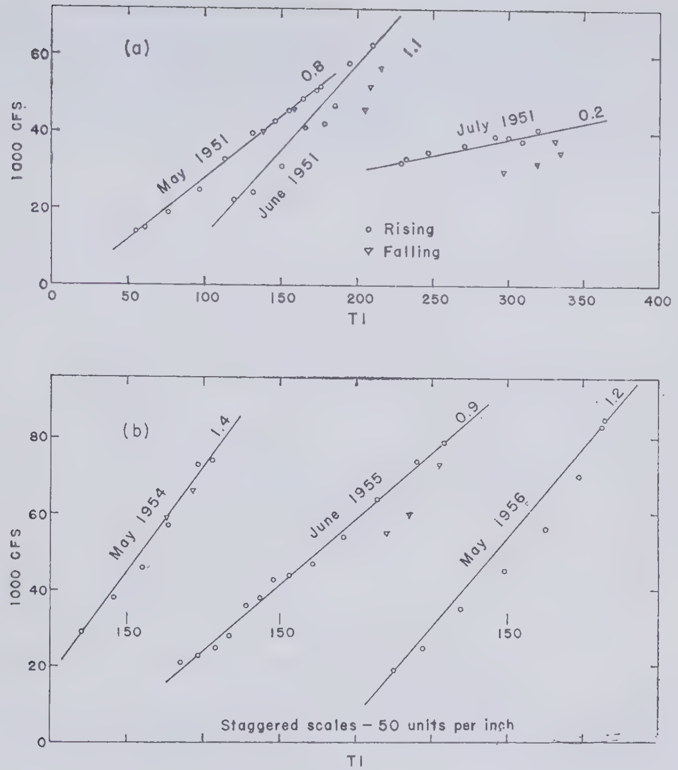

Fig. 4

The slope of the curves is a function of the effective contributing area. It is low at the beginning of the season when the snow pack has not yet ripened. It rises to a maximum value, and then recedes with the decrease in snow covered area. The numerical slope values shown are with reference to a value of 1.0 for a 45 degree line, and are to be used in the next section of this paper. Because contributing area normally changes slowly, the $TI - Q$ curve can be extrapolated successfully for the usual three day forecast without knowledge of the actual contributing area. The importance of snow cover knowledge increases with the extension of the forecast.

The Contributing Area Index

Many different approaches to the determination of contributing area have been made (1) (2). Perhaps the most satisfactory method is that of aerial reconnaissance as praticed by the several District Offices of the Corps of Engineers. However, an inexpensive method of continuous appraisal of snow covered area would be welcomed by both flood forecasters and those concerned with reservoir regulation and water management. I would like to suggest an approach which seems to have merit and warrant further study.

To introduce the method let us visualize two adjacent hypothetical basins, identical in every respect except the distribution of area with elevation. They will be affected by the same

...each will receive a uniform basin-wide snow cover. Figure 5(a) shows the respective ...vation relations and (b), the relation between the two basins. If we now apply a gra... ...increasing amount of heat, just sufficient to cause melting over a narrow elevation ... a graph of the accumulated discharges from the two basins would follow a curve identica... ...ape to Figure 5(b). We could simply re-label the scales and call them percent of accumulated ...asonal runoff. The slope of the curve would indicate the elevation of the snow line or the ...ffective contributing area throughout the season.

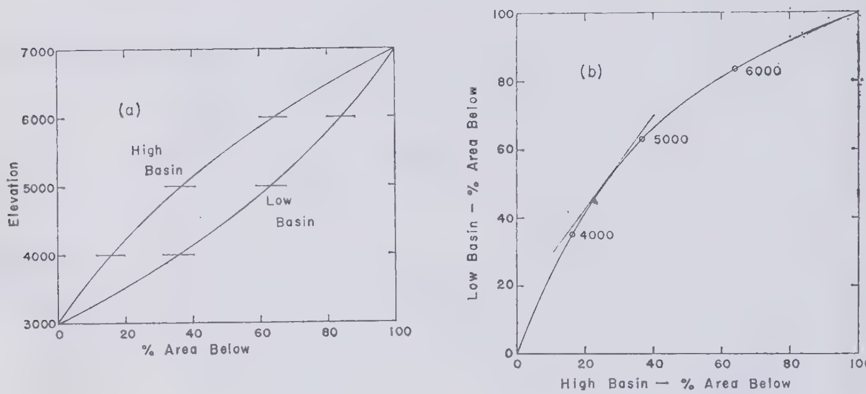

Fig. 5

The illustration is far-fetched, but there are, nevertheless, natural basins which exhibit these characteristics to a useful degree. Figure 6 shows the accumulated April-July runoff relation between the Salmo River (See Figure 1) and adjacent Kootenay Lake Local Inflow. Years plotted include the largest (1954), and smallest (1958), of Salmo record, but all unplotted years fall within these envelopes.

If these basins were more nearly the same size we could use the slope of the curve in Figure 6 as an index to contributing area, but differing recession characteristics and the influence

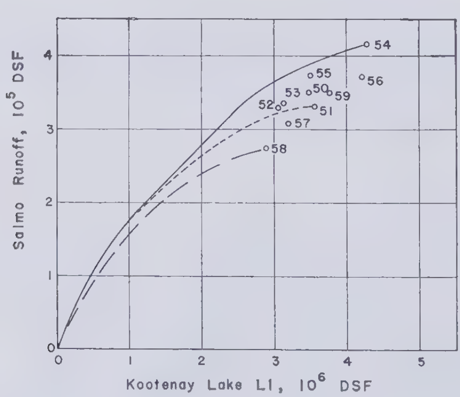

Fig. 6

of rainfall runoff make it preferable to compare only periods of active snowmelt. [illegible] the horizontal scale is the ratio of trough-to-peak rise in the Salmo River to rise in the Inflow for the previous period of snowmelt. (Units in the ratio of 10: 1, compatible with [illegible] are assumed). The vertical scale is the slope of the $TI-Q$ curve for the current rise as prev[illegible] shown in Figure 4. Table 1 identifies the points.

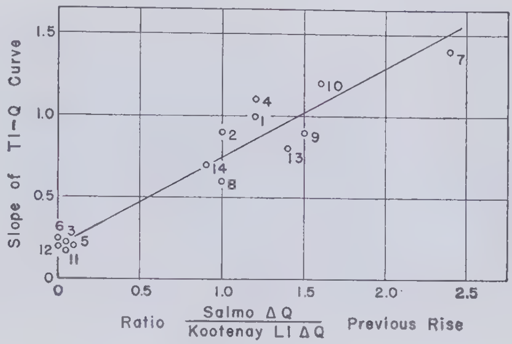

Fig. 3

TABLE 1

Contributing Area Index Data

Point N°.	Year	Dates of Current Rise	Dates of Previous Rise
1	1950	June 10-15	June 1-5
2	1950	June 16-22	June 10-15
3	1950	June 27-July 7	June 16-22
4	1951	June 9-16	May 21-24
5	1951	July 11-18	June 29-July 5
6	1953	July 6-15	June 29-July 5
7	1954	May 16-21	May 2-11
8	1954	June 21-28	June 10-14
9	1955	June 2-14	May 16-22
10	1956	May 15-22	May 6-10
11	1956	July 8-14	June 27-29
12	1957	May 26-June 7	May 7-10
13	1958	May 19-25	April 30-May 11
14	1959	June 19-23	June 12-15

A general relation between the two values is evident, although the usable data are not uniformly distributed. Perhaps the most consistent feature is the apparent limiting slope of about 0.2 for a zero ratio. A zero ratio is computed when the Salmo flow remains steady or

declines during a rise in Local Inflow. The condition indicates a depleted snow cover and ha occurred as early as May. It imposes a limit on the extent of a subsequent snowmelt rise an should help to answer the perennial late season question, "Have we had the peak?" In oth words, is there sufficient snow cover that the forecast temperatures, or any reasonably possib sequence of high temperatures can produce a peak flow higher than has already occurred

Summary

The temperature index is well suited to operations of the River Forecast Center whe temperature reports and forecasts are available early in the morning and river reports com somewhat later. The three day forecast *TI* is ready and the *TI*= *Q* curve can be extended fo a three day discharge forecast as soon as today's discharge is known.

While mean temperature excess was used in this study, the method imposes no restriction We have also used maximum temperature, a composite temperature and dewpoint functio and upper air temperatures in various other basins.

The contributing area index provides an independent check on other methods—it lets th basin tell its own story of snow cover depletion. If studies in other areas prove the inde useful, by itself or in conjunction with other observations, then a reporting service from sma index basins would be warranted.

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BIBLIOGRAPHIE

PAR

W. LÁSZLÔFFY (*Budapest-Hongrie*)

Kolupaila, Steponas, Dr. Eng. : *Bibliography of Hydrometry.* University of Notre Dame Press, Notre Dame, Indiana, 1961. XXIII + 975 pages, 1 tableau. Prix : 10 $.

La parution de ce volume de 975 pages a fait événement dans les milieux des hydrologues du monde entier. Il constitue un excellent recueil de 7370 titres très soigneusement groupés des travaux de 4500 auteurs. L'auteur s'efforce d'embrasser toute la bibliographie mondiale de l'hydrométrie. Il est attentif à tout, depuis les vestiges archéologiques de l'hydrométrie égyptienne et d'Asie Centrale jusqu'à la littérature de l'année 1960 des procédés hydrométriques basés sur les principes électromagnétique, d'ultrason ou gyroscopique.

Cette matière énorme a été divisée en 26 chapitres comprenant 254 sous-titres et dans l'introduction de chaque chapitre et, au besoin, de chaque sous-titre, l'auteur donne un bref aperçu historique et technique des matières respectives.

L'énumération suivante des titres donne la mesure de la matière traitée par cet ouvrage monumental. (Le nombre des sujets autonomes entre parenthèses) :

A. Traités de l'hydrométrie, manuels, ouvrages généraux (*150*) — *B.* Observation des niveaux d'eau (*922*). — *C.* Élaboration des données d'observations limnimétriques (*330*). — *D.* Calcul des débits (*456*). — *E.* Instruments hydrométriques (*933*). — *F.* Étalonnage des instruments de mesure de la vitesse (*214*). — *G.* Équipement des stations hydrométriques (*288*). — *H.* Procédés de jaugeage de débits (*379*). — *I.* Mesure de la vitesse dans les conduites (*147*). — *J.* Mesures au moyen de traceurs (*225*). — *K.* Méthode Gibson (*53*). — *L.* Jaugeage volumétrique (*25*). — *M.* Orifices et vannes (*167*). — *N.* Diaphragmes et tuyères (*233*). — *O.* Tubes de Venturi (*229*). — *P.* Déversoirs et jaugeurs à ressaut (*623*). — *Q.* Procédés physiques modernes (*92*). — *R.*Compteurs d'eau (*52*). — *S.* Procédés basés sur la mesure de la pente et de la superficie du profil (*101*). — *T.* Mesure de la profondeur (*93*). — *U.* Mesures sur les rivières à marée (*96*). — *V.* Mesure du débit solide (*219*). — *W.* Mesures hydrométéorologiques (*194*). — *X.* Mesures des qualités des liquides (*15*). — *Y.* Sources des données hydrométriques (210). — *Z.* Bibliographies (*30*).

Pour donner une idée du classement détaillé de la matière on pourrait citer à titre d'exemple les sous-titres du chapitre *B.* (entre parenthèses le nombre des titres mentionnés) :

L'histoire des stations limnimétriques (*33*). — Marques de crue (*5*). — Choix de l'emplacement des limnimètres (*12*). — Nivellement du zéro des échelles (*17*). — Échelles limnimétriques (*12*). — D'autres types de limnimètres (*14*). — Échelles limnimétriques à maxima et à minima (*38*). — Instruments de précision pour indiquer le niveau d'eau (*17*). — Indicateurs de niveau d'eau (*55*). — Échelle à transmission différentielle (*15*). — Instruments pour mesurer les variations du niveau des eaux souterraines (*39*). — Échelle pneumatique et hydraulique (*43*). — Limnigraphes, maréographes (*114*). — Échelle à enregistrement photographique (*26*). — Échelle indiquant le débit par transmission mécanique (*34*). — Télélimnimètres (*88*). — Équipement des stations limnimétriques. Abri du limnigraphe (*59*). — Seuil de contrôle (*22*). — Prise de pression (*27*). — Entretien des stations limnimétriques (*30*). — Entretien des limnigraphes (*22*). — Précisions des limnigraphes (*20*). — Organisation du service d'observation et normalisation (*42*). — Observation des hauteurs d'eau (*89*). — Observation de la température de l'eau (*28*). — Étude du régime des glaces (*67*).

Notre époque est celle de la documentation organisée, aussi du point de vue des recherches la langue et le lieu de parution d'un travail scientifique est de peu d'importance. Grâce au microfilm tous les ouvrages en n'importe quelle langue sont à la portée de tout le monde et on peut facilement en avoir des traductions. Les produits intellectuels de tous les peuples, majeurs et mineurs, sont important au même degré. C'est donc le fait qu'il *documente sur la littérature technique de 36 langues* qui constitue l'intérêt inappréciable de l'ouvrage du professeur Kolupaila. La force numérique des peuples étant très différente et leur littérature technique à un niveau de développement fort différent, il est difficile de conclure à des jugements de valeur sur

la base des chiffres. Citons toutefois à titre d'exemple que dans le chapitre des déversoirs et des jaugeurs à ressaut 42% des titres cités est anglais, 31% allemand, 10-10% français et russe, 2% italien et le reste — 5% — est réparti entre 17 autres langues. Le travail de collection est vraiment très consciencieusement accompli.

Une des conditions requises pour faire une bibliographie c'est qu'elle soit faite *soigneusement*. De ce point de vue aussi l'ouvrage du professeur Kolupaila peut être qualifié de sans-pareil. Comme il le dit dans l'introduction, 90% des titres cités sont pris directement de l'original, ainsi il a éliminé autant que possible les erreurs inhérentes aux citations indirectes et leurs fautes souvent fâcheuses. Les annotations en quelques mots, qui suivent les données bibliographiques nous renseignent non seulement sur le contenu de l'ouvrage, mais encore elles contiennent une appréciation et des références. La bibliographie donne aussi le lieu où les ouvrages rarissimes peuvent être consultés. L'auteur renseigne les analyses publiées ailleurs des ouvrages cités, ainsi que les traductions et les éditions ultérieures, s'il y a lieu. (De sorte que le nombre réel des références dépasse largement les chiffres susmentionnés). Le nom des auteurs d'articles signés des initiales seulement, a été également rapporté, pour autant que l'on ait réussi à en établir l'identité. Le professeur Kolupaila a apporté un grand soin à l'index des auteurs également. Il donne autant que possible leur prénom complet, l'année de leur naissance et (le cas échéant) de leur mort.

L'intérêt pratique de ce livre est d'autant plus grand que tout en donnant pour les ouvrages énumérés les annotations et les lieux de leurs analyses parues dans d'autres publications ou en d'autres langues, l'auteur énumère les titres d'ouvrages dans chaque chapitre suivant l'ordre chronologique, en indiquant en marge, d'une manière visible marquante, à l'aide des symboles, la langue des ouvrages communiqués et, dans le cas des articles, le titre tout entier de la revue en question afin d'éviter les méprises dues aux abréviations.

Le professeur Kolupaila a passé une grand partie de sa vie à organiser et à diriger le service hydrométrique lithuanien. Voilà pourquoi le centre de son ouvrage se porte sur les problèmes hydrométriques relatifs aux eaux de surface. En conséquence les problèmes hydrométriques des conduites d'eau et des machines hydrauliques, ou par exemple, la bibliographie des mesures hydrométéorologiques sont traitées comme des sujets marginaux, bien qu'il ne fournisse, là encore, en publiant le titre de bibliographies spéciales, plus que nous ne le pensions au premier abord.

Cette bibliographie sera particulièrement appréciée par les *investigateurs de l'histoire de la technique*, parce que l'exploration du passé de l'hydrométrie a tenu à cœur à l'auteur, ce qui est prouvé notamment par le fait qu'il cite 34 communications relatives aux nilomètres antiques, qu'il énumère 37 publications, éditions ou traductions de l'ouvrage célèbre de Vitruve (Marcus Vitruvius Pollio) «De architectura, libri X» et qu'il enrichit son ouvrage d'une gravure symbolisant le domptage du fleuve Tibre, l'ancien Tiberis, gravure provenant de l'ouvrage rarissime de F.M. Bonini, publié en 1663.

La question se pose d'elle-même, comment cette œuvre monumentale ait pu être réalisée? Dans la préface l'auteur memtionne les noms des 47 collaborateurs provenant de différents pays. Cependant nous pouvons lire à la même place que l'auteur avait collectionné les matériaux dès sa jeunesse : déjà en 1921 il a publié un recueil bibliographique comportant 592 titres et pendant la deuxième guerre mondiale, au cours des plus dures années de sa vie il a continué le travail de recherche dans les bibliothèques de l'Allemagne détruite. Nous connaissons les deux volumes de son Hydrométrie, parue en 1939-1940, en langue lituanienne, et nous savons qu'il a publié déjà en 1918, en langue russe un manuel de moindre dimension traitant le même sujet. Donc les collaborateurs étrangers énumérés dans le livre ne l'ont assisté que dans une faible mesure tout au plus. Au fond, *c'est l'œuvre d'un savant d'une érudition prodigieuse, admirablement studieux et consciencieux, digne de l'approbation sincère et reconnaissante des hydrologues du monde entier.*

Les spécialistes des petits peuples doivent être particulièrement reconnaissants à l'auteur puisqu'ils cultivent, conformément à leur obligation morale envers leur patrie, la littérature

scientifique dans leur langue maternelle et, à cause de cela, en général, ils sont omis sur les bibliographies internationales.

* * *

Qu'il me soit permis de parler, en concluant, de la *mise à jour et de la continuation* de l'ouvrage du professeur Kolupaila. Il est certain qu'aucune œuvre humaine ne peut être complète. Cette Bibliographie de l'Hydrométrie une fois publiée, chacun de nous peut la contrôler et établir la liste des titres qui pourraient la compléter. Nul doute que cet ouvrage—qui remonte jusqu'aux origines les plus anciennes de l'hydrométrie et qui restera toujours un ouvrage de base — ne soit digne d'être mis à jour de façon constante dans l'avenir aussi. Les matériaux pourraient être fournis par les Comités Nationaux de l'Association Internationale d'Hydrologie Scientifique et la «*University of Notre Dame Presse*», qui a publié le présent volume d'une présentation impeccable avec la subvention du «National Science Foundation» américain, pourrait peut-être pourvoir à la publication des suppléments, ce qui lui demanderait beaucoup moins de sacrifices que ce premier vaste volume.

III. PARTIE ADMINISTRATIVE
III. ADMINISTRATIVE PART

A) A. I. H. S.

a) MEETING OF THE COUNCIL OF THE ASSOCIATION ATHENS 13th, 16th AND 17th OCTOBER 1961.

Chairman: Dr W. FRIEDRICH

AGENDA

1) Organization of an International Decade in Hydrology — American Proposal.

2) Program of the General Assembly in 1963.

3) Proposal of the Committee of U.K. regarding the Bulletin.

4) Relations with UNESCO.

5) Relations with W.M.O.

6) Relations with F.A.O.

7) Relations with other Organizations.

I. International Decade

The Secretary received from the Ad Hoc Panel on Hydrology of the U.S.A :

"A Proposal for International Cooperation in Hydrology" and "A Plan for International Cooperation in Hydrology".

Both texts are reproduced in the Scientific Part of this Issue.

Mr Nace exposed the question. After a discussion, the Council asked the Secretary to prepare a text of resolution. The following text was adopted without discussion :

A) I. A. S. H.

a) RÉUNION DU CONSEIL DE L'ASSOCIATION A ATHÈNES, LES 13, 16 ET 17 OCTOBRE 1961.

Président : Dr. W. Friedrich

AGENDA

1) Organisation d'une décade internationale hydrologique — Proposition américaine.

2) Programme de l'Assemblée Générale de 1963.

3) Proposition du Comité du R.U. au sujet du Bulletin.

4) Relations avec l'Unesco

5) Relations avec l'O.M.M.

6) Relations avec la F.A.O.

7) Relations avec d'autres organisations.

I. Duade Internationale

Le Secrétaire a reçu les documents suivants de l'AdHoc Panel on Hydrology of the U.S.A :

«A Proposal for International Cooperation in Hydrology» and «A Plan for International Cooperation in Hydrology».

Ces deux documents sont reproduits dans la partie scientifique de ce Bulletin.

Monsieur Nace expose la question.

Après discussion, le Conseil demande au Secrétaire de préparer un texte de résolution.

The Council of the I.A.S.H. took note, with great interest of the proposals of the Federal Council of Science and technology and, in particular, of the "proposal for International Cooperation in Hydrology" and of the proposed "Plan for International Cooperation in Hydrology" by the "Ad Hoc Panel on Hydrology".

The Council appreciates the opportunity to consider this proposal. However it appears that a decision on this matter cannot be taken in Athens: the question must be discussed in detail by the National Committees.

However the latter should be invited to take their decision on the principle, within a relatively short period—early 1962 could be considered as a dead line for informing the Secretariat of their decision.

The Council considers that apart from I.A.S.H., and, later I.G.G.U., other organisations should be informed of the proposal so as to see to it, that, if the idea were to develop, a Committee could be set up, including in particular, representatives of I.G.G.U. (A.I.H.S.) UNESCO, W.M.O. and F.A.O.

Le texte suivant est adopté sans discus-sion :

Le Conseil de l'A.I.H.S. a pris connais-sance avec beaucoup d'intérêt des propo-sitions du Federal Council on Science and Technology et notamment de la «Proposal for International Cooperation in Hydrology» et du «Plan for International Cooperation in Hydrology» établis par l'«Ad Hoc Panel on Hydrology».

Il remercie le Federal Council on Science and Technology de l'honneur fait à l'A.I.H.S. en la choisissant pour introduire cette proposition.

Le Conseil estime qu'une décision sur cette proposition ne peut être prise à Athènes : la question doit en effet être largement dis-cutée par les Comités Nationaux. Il convient cependant d'inviter ces Comités à prendre leur décision de principe dans un délai assez court : le début de 1962 pourrait être choisi pour le délai à fixer pour l'envoi des réponses au Secrétaire.

Le Conseil estime qu'à côté de l'A.I.H.S. et par suite de l'U.G.G.I., d'autres orga-nisations devraient être mises au courant de la proposition, de façon que si l'idée prend corps, un comité puisse être constitué comprenant notamment des représentants de l'U.G.G.I. (A.I.H.S.) de l'UNESCO, de l'O.M.M. et même de la F.A.O.

II Program of the General Assembly of 1963 in Berkeley

The Secretary read the circulate I and II he sent some months ago (the text of these circulaires was published in the Bulletin VI.2).

a) Symposium U.G.G.I. on the Upper Mantle 1963 (Circulaire II). After a long discussion, it was decided that the Association would not take part to this Symposium, but that members of the Association may collaborate to this Symposium.

b) Symposia in 1962.

The Secretary presented some details concerning these 2 symposia (See Bulletin VI n° 1). The secretary announced that a grant of UNESCO was proposed by the Advisory Committee of Arid Zones for the Symposium on Land Erosion.

II. Programme de l'Assemblée Générale en 1963 à Berkeley

Le Secrétaire donne lecture des circulaires I et II qu'il a envoyées, il y a quelques mois (les textes de ces circulaires ont été publiés dans le bulletin).

a) Colloque U.G.G.I. sur le «Upper Mantle» 1963 (circulaire II). Après une longue discussion, il est décidé que l'Association ne prendra pas part à ce colloque, mais que ses membres seront libres d'y participer.

b) Colloques de 1962

Le Secrétaire donne quelques détails au sujet de ces deux colloques (voir Bulletin VI n° 1). Il annonce que le Comité Consultatif de la Zone Aride a proposé à l'Unesco d'accordér une subvention pour le colloque sur l'Erosion Continentale.

c) General Assembly of Berkeley in 1963.

Some delegates not wish to hold symposia in Stanford during the week before the General Assembly. Prof. TODD however exposed that the section of Hydrology of the A.G.U. would like that the Association organize symposia during this week.

After a long discussion the Secretary was charged by the Council to prepare the Agenda of 1963.

c) Assemblée Générale de Berkeley en 1963.

Certains délégués ne désirent pas tenir de Colloque à Stanford au cours de la semaine précédant l'Assemblée Générale. Le professeur Todd expose cependant que la section d'hydrologie de l'A.G.U. désirerait organiser de colloques au cours de cette semaine. Après une longue discussion, le Conseil charge le Secrétaire de préparer l'ordre du jour de 1963.

III. Bulletin of the I.A.S.H.

The Secretary received from the Committee of the U.K. the following resolution:

III. Bulletin de l'A.I.H.S.

Le Secrétaire a reçu du Comité du R.U. la résolution suivante :

THE ROYAL SOCIETY

Burlington House, London, W. 1
Regent 3335
NGG/7/KMC
20 July 1961

Dear Professor Tison,

IASH Bulletin

I have been requested by the Hydrology Sub-Committee of the British National Committee for Geodesy and Geophysics to convey to you the following resolution passed at a meeting of the Sub-Committee held on 10 July last:

"That the General Secretary of the International Association of Scientific Hydrology be informed that the Hydrology Sub-Committee of the British National Committee for Geodesy and Geophysics:

expresses its appreciation of the services rendered to the IASH by Professor Tison and his family, not least in the field of publication;

wishes to ensure that Professor Tison and M. Gerard Tison will continue to take parts in the preparation and supervision of growing international hydrological publications;

hopes that professor Tison and the North-Holland publishing Company (now preparing publication of an independent Journal of Hydrology) will work out a basis for collaboration so that a single international publication may be produced for the benefit of hydrologists in all countries supporting the IASH, combining the editorial strength of the IASH with the commercial strength of the North-Holland Publishing Company, and

recommends that Professor Tison inform the various National Committee of the position as regards international Hydrological journals, by mail, in time for it to be discussed at the next meeting of the Council in Athens in October 1961.

Yours sincerely

Assistant Secretary

Mr SHAW presented the British Resolution.

Most of the Members of the Council prefer the continuation of the existing situation. It is also the wish of some countries which are not represented at this meeting of the Council but wrote to the Secretary.

In these conditions, the Chairman expressed the view that the publication of the Bulletin will continue in the present conditions—Adopted.

Mr SHAW présente la résolution britanique. La plupart des membres du Conseil préfère que le Bulletin continue à être publié comme il l'a été jusqu'ici. C'est aussi le désir de plusieurs pays non représentés aujourd'hui au conseil, mais qui ont fait connaitre leur opinion par écrit.

Dans ces conditions, le Président exprime l'opinion que la publication du Bulletin doit être continuée comme par le passé. Adopté.

IV. Relations with UNESCO

The Secretary exposed the good results of the Collaboration with UNESCO.

IV. Relations avec l'Unesco

Le Secrétaire expose les bons résultats de la collaboration avec l'Unesco.

V. Relation with W.M.O.

Bulletin VI 3 presented a large summary of the General Report of the First Session of the Commission of hydrological Meteorology of W.M.O. (April 1961 — Washington D.C.).

Mr VOLKER presents some of the favorable results of this Session.

V. Relations avec l'O.M.M.

Le Bulletin VI. 3 présente un large résumé du Rapport de la première session de la Commission de Météorologie hydrologique de l'O.M.M. (Avril 1961 — Washington D.C.).

Mr VOLKER insiste sur quelques résultats favorables de cette session.

VI. F.A.O.

The Bulletin VI n° 1 presented some results of a meeting of F.A.O. in Paris.

VI. F.A.O.

Le Bulletin VI n° 1 présente quelques résultats d'une réunion organisée par la F.A.O. à Paris.

VII. Other Organizations

No special communications.

VII. Autres Organisations

Rien de spécial.

b) SYMPOSIUM OF OBERGÜRGL

VARIATIONS OF THE REGIME OF EXISTING GLACIERS

(See Issue VI n° 1 of the Bulletin). This symposium will be hold from Monday 10th to Tuesday 18th September 1962. The abstracts (3 copies) in both English and French must be sent to the Secretary of the Commission (147 Rickmansworth Road,

b) COLLOQUE D'OBERGURGL

VARIATIONS DU RÉGIME DES GLACIERS EXISTANTS

Rappelons qu'il aura lieu du 10 ou 18 Septembre 1962 (voir le VI n° 1).

Les résumés (en 3 exemplaires) en français *et* anglais sont à envoyer avant le 1er Février 1962 au Secrétaire de la Commission (147 Rickmans Worth Road, Wat-

Watford, Herts, England) not later than February 1, 1962.

The complete texts (3 copies) have to be sent at the same address before April 1, 1962.

There are at the moment 75 attendants with 40 offers of papers.

ford, Herti, England) Les textes complets (en 3 exemplaires) doivent lui parvenir avant le 14 Avril 1962.

Au 1er novembre, il y avait 75 participants inscrits avec 40 présentations de communications.

c) SYMPOSIUM OF BARI

LAND EROSION

The program was published in Bulletin VI nº 1. The Symposium wil take place during the first week of October 1962 : 4 days for working sessions and 2 days for excursion.

The meeting will take place at the University of Bari.

The abstracts (2 copies) in both French and English have to be sent to the Secretary of the Association (61, rue des Ronces, Gentbrugge, Belgique) befor Februari 1, 1962 and the complete texts (2 copies) before June 1, 1962.

c) COLLOQUE DE BARI

EROSION CONTINENTALE

Le programme a paru dans le bulletin VI nº 1. Le colloque aura lieu durant la première semaine d'octobre 1962 : 4 journées de travail et 2 journées d'excursion.

Les réunions se feront à l'Université de Bari.

Les résumés (2 exemplaires) en français *et* anglais doivent parvenir au Secrétaire de l'Association, L.J. Tison avant le 1er février 1962 et les textes complets (2 exemplaires) avant le 1er juin 1962.

PUBLICATIONS DE L'A. I. H. S.

encore disponibles

I. COMPTES-RENDUS ET RAPPORTS

Publ. n° 3 — 1926 — Notes et communications		50	F Belges
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Publ. n° 8 — Id.		25	»
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Publ. n° 17 — 1931 — Communications à Stockholm		50	»
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Publ. n° 49 — Symp. Hannoversch Münden. Lysimètres	150	»
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Assemblée de Helsinki 1960

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Publ. n° 55 — Colloque sur l'Antarctique	150	»
Publ. n° 56, Publ. n° 57 — Colloque Athènes	500	»

II. BIBLIOGRAPHIE HYDROLOGIQUE

1934 (Egypte, France, Indes, Italie, Lettonie, Maroc, Pays Baltes, Roumanie, Suède, Suisse, Tchécoslovaquie, Tunisie, Pologne — en 1 vol. 100 F Belges

Argentine

début à 1954 — 25 FB.

Allemagne

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Egypte

début à 1954 — 10 FB.

Etats-Unis (+ Canada)

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1941-1950 — 100 FB.
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Pays-Bas

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Portugal

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Afrique du Sud

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Autriche

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Espagne

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Yougoslavie

du début à 1954-20 FB.

Hongrie

1945-1954 — 50 FB.
1955-1958 — 50 FB.

Israël

1945-1949 — 20 FB.
1949-1955 — 25 FB.

III. BULLETIN DE L'ASSOCIATION D'HYDROLOGIE

Ce bulletin paraît quatre fois l'an depuis 1956. Il comprend une partie réservée à l'information et une partie scientifique.

Prix de l'abonnement : 250 FB.

IV. PUBLICATIONS DIVERSES

1.	Quelques études présentées à Washington 1939	50 F Belges
2.	Crues de 1954 — 1 publ. autrichienne	40 »
3.	Rapports de l'Inde au Symposia Darcy à Dijon	50 »
4.	Classification décimale hydrologique en Pologne	25 »

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